THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY

No. 167 December, 1939 Vol. XXV

Tektites and silica-glass.

(With Plates XVI and XVII.)

By L. J. Spencer, C.B.E., M.A., Sc.D., F.R.S.

Formerly Keeper of Minerals in the British Museum.

[Read November 9, 1939.]

THE natural glasses recognized as tektites are characterized by their acidic composition, the silica percentage ranging from 68 to 80. Their origin is still a debatable point. Within this range glasses are known which have undoubtedly been produced by the fusion of siliceous terrestrial materials in the intense heat developed when large iron meteorites have struck the earth's surface; while others of the same origin show silica ranging up to 98 per cent., that is, an almost pure silica-glass.

From a collection of 84 chemical analyses of tektites taken from the literature, only 36 (many of them due to A. Lacroix) give data for the specific gravity and refractive index which presumably were determined on the same sample of material as that analysed. These are reproduced in table I (arranged in order of silica percentages) and plotted in figs. 1 and 2. Corresponding with the range in SiO_2 from 68·00 to 80·73 % there is a nearly uniform decrease in d (2·498–2·339) and n (1·526–1·4867). The specific refractivity, $K = (n-1)/d$, varies from 0·2050 to 0·2107 (0·2258 in the case of no. 29 with the abnormally high n 1·5380).

TABLE I. Chemical analyses, specific gravity, and refractive indices of tektites (from the literature).

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	Na_2O.	K_2O.	Sp.gr.	n_D.
68·00	16·46	—	6·08	3·38	2·00	1·45	1·84	2·465	1·5178
68·60	15·80	0·18	6·46	2·88	1·40	2·35	1·92	2·487	1·5146
69·32	12·27	0·06	6·81	4·05	3·72	0·77	2·18	2·498	1·526
70·08	13·61	0·15	4·81	2·16	3·48	1·99	2·44	2·443	1·5148
70·28	12·67	0·20	5·28	2·62	3·92	1·71	2·32	2·457	1·5157

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	Na_2O.	K_2O.	Sp.gr.	n_D.
6.	70·40	13·65	0·17	5·13	1·94	3·00	1·57	2·72	2·440	1·5120
7.	70·56	20·54	—	0·96	0·11	0·78	3·47	3·38	2·359	1·4855
8.	70·58	13·23	0·10	5·08	1·92	3·92	1·43	2·59	2·445	1·5146
9.	70·62	12·34	2·25	3·17	3·61	2·99	1·68	1·57	2·442	1·51
10.	70·66	12·08	1·78	4·52	3·65	2·97	1·62	1·69	2·439	(1·51)
11.	70·90	13·50	0·32	5·47	2·45	2·35	1·46	2·17	2·457	1·5097
12.	71·20	13·52	0·59	3·89	2·23	3·40	1·59	1·84	2·436	(1·51)
13.	71·32	12·16	2·03	3·03	2·94	2·95	1·66	1·90	2·431	(1·51)
14.	71·45	12·54	0·51	4·61	2·72	2·82	1·44	2·41	2·442	1·5113
15.	71·64	12·53	—	5·32	2·79	3·42	1·21	2·28	2·447	1·5130
16.	72·08	13·21	0·37	4·47	1·92	2·42	1·61	2·80	2·422	1·5063
17.	72·12	12·88	—	4·99	2·04	3·14	1·45	2·28	2·432	1·5089
18.	72·26	13·18	—	5·32	2·15	2·42	1·42	2·15	2·440	1·5133
19.	72·40	12·68	0·23	3·59	2·34	2·75	1·68	3·16	2·409	1·50
20.	72·48	12·84	—	4·59	2·16	2·78	1·73	2·63	2·429	1·5089
21.	72·62	12·20	—	5·19	2·20	2·28	2·00	2·17	2·421	1·5042
22.	72·78	12·20	—	5·33	2·30	2·52	1·69	2·09	2·414	1·5053
23.	73·14	12·48	—	4·88	2·12	3·34	1·29	1·84	2·429	1·5076
24.	73·30	11·98	—	5·19	2·44	2·28	1·64	2·25	2·429	1·5058
25.	73·73	11·33	0·83	4·46	2·39	2·49	1·15	2·32	2·436	1·5091
26.	74·14	12·73	—	4·93	1·78	2·24	1·03	2·41	2·419	1·5035
27.	74·56	12·34	—	4·66	1·82	2·40	0·92	2·47	2·419	1·5045
28.	74·56	12·60	—	4·98	1·22	1·34	1·81	2·21	2·404	1·4986
29.	74·91	13·80	0·44	3·10	1·66	1·16	0·72	3·76	2·383	1·5380
30.	76·56	11·54	0·17	3·99	3·60	1·62	1·32	0·82	2·4	1·4991
31.	76·64	11·36	0·06	4·39	1·29	1·48	1·56	2·30	2·413	1·4972
32.	77·08	10·66	0·36	1·78	2·20	3·74	0·54	3·33	2·395	1·5033
33.	78·75	10·99	0·54	1·43	1·75	2·38	0·51	3·01	2·352	1·4891
34.	80·00	10·04	—	2·27	1·46	1·76	0·51	3·37	2·339	1·4877
35.	80·52	9·44	—	1·98	1·73	1·84	0·52	3·15	2·341	1·4875
36.	80·73	9·61	—	1·93	1·59	2·13	0·37	3·60	2·343	1·4867

1. Akakoumoekrou, Ivory Coast, West Africa. A. Lacroix, 1934, 1935. Analyst, F. Raoult; also TiO_2 0·80, MnO 0·09, H_2O+ 0·13, H_2O- 0·14; total 100·37.
2. Ouellé, Ivory Coast, West Africa. A. Lacroix, ibid. Analyst, F. Raoult; also TiO_2 0·80, MnO 0·06; total 100·45.
3. Martapoera, Borneo. A. Lacroix, 1932, pp. 193, 203. Analyst, F. Raoult; also TiO_2 1·01, MnO 0·09, H_2O+ 0·14, H_2O- 0·11; total 100·53.
4. Malaya. A. Lacroix, 1929, 1931, 1932. Analyst, F. Raoult; also TiO_2 0·79, MnO 0·15, H_2O- 0·08; total 99·74.
5. Billiton, Dutch East Indies. A. Lacroix, 1929, 1931, 1932. Analyst, F. Raoult; also TiO_2 1·10, MnO 0·19, H_2O- 0·05; total 100·35.
6. Attopeu, Laos, French Indo-China. A. Lacroix, 1930, 1932, 1935. Analyst, F. Raoult; also TiO_2 1·03, MnO 0·15, H_2O- 0·16; total 99·92.
7. Paucartambo, Peru. G. Linck, 1926, 1928. Also, some MnO included with FeO, ign. loss 0·83; total 100·63. Contains various unusual crystallites.
8. Tan-hai island, Kwang-chow-wan, south China. A. Lacroix, 1930, 1932, 1935. Analyst, F. Raoult; also TiO_2 0·99, MnO 0·13, H_2O+ 0·20; total 100·17.
9. Kaliosso, Soerakarta, Java. C. M. Koomans, 1938. Also TiO_2 0·62, MnO 0·10, P_2O_5 0·12, H_2O+ 0·75; total 99·82.
10. 'Rizalite': Philippine Islands. C. M. Koomans, 1938. Also TiO_2 0·63, MnO 0·16, P_2O_5 0·18, H_2O+ 0·15; total 100·09.

1. Tutong, Brunei, British Borneo. F. P. Mueller, 1915. Analyst, Hinden; also TiO_2 1·00 about, MnO trace; total 99·62.
2. Bulakda, Philippine Islands. C. M. Koomans, 1938. Also TiO_2 0·92, MnO 0·08, P_2O_5 0·10, H_2O+ 0·63; total 99·99.
3. Busuanga, Philippine Islands. C. M. Koomans, 1938. Also TiO_2 1·04, MnO 0·11, P_2O_5 0·13, H_2O+ 0·51; total 99·78.
4. Philippine Islands. F. Heide, 1938. Analyst, P. Wagner; also TiO_2 1·02, MnO 0·10, P_2O_5 0·38, H_2O+ 0·24, H_2O- 0·04; total 100·28. Spectroscopic traces of Ni, Cr, Sr, Ba, Zr, V, Cu, Ga.
5. Rosario, prov. Batangas, Philippine Islands. A. Lacroix, 1931, 1932. Analyst, F. Raoult; also TiO_2 0·98, MnO 0·10, H_2O+ 0·19, H_2O- trace; total 100·46.
6. Smach (= Schmach), Cambodia, French Indo-China. A. Lacroix, 1929, 1930, 1932, 1935. Analyst, F. Raoult; also TiO_2 0·78, MnO 0·13, H_2O+ 0·13, H_2O- 0·13; total 100·05; corrections in later publications.
7. Beausite, Pia Cac, Tonkin, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 1·00, MnO 0·13, H_2O+ trace, H_2O- 0·04; total 100·07.
8. Dan-kia, Annam, French Indo-China. A. Lacroix, 1931, 1932, 1935. Analyst, F. Raoult; also TiO_2 0·99, MnO 0·10, H_2O+ 0·14, H_2O- 0·06; total 100·20.
9. Dhupan hill, Siam. C. M. Koomans, 1938. Also TiO_2 0·74, MnO 0·06, P_2O_5 0·14, H_2O+ 0·43; total 100·20.
10. South of Muong Nong, Laos, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 1·01, MnO 0·11, H_2O+ 0·14, H_2O- 0·05; total 100·52.
11. Near Kratié, Cambodia, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·94, Cr_2O_3 0·01, MnO 0·11, H_2O- 0·17; total 99·89.
12. Dalat, Lang Bian, Annam, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·90, Cr_2O_3 0·03, MnO 0·12, H_2O- 0·07; total 100·03.
13. Dong Van, Tonkin, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·95, MnO 0·16, H_2O+ 0·21, H_2O- 0·09; total 100·50.
14. Dalat, Lang Bian, Annam, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·99, Cr_2O_3 0·01, MnO 0·32, H_2O+ 0·12, H_2O- 0·14; total 100·46.
15. Solo, central Java. F. Heide, 1939. Analyst, P. Wagner; also TiO_2 0·87, MnO 0·11, P_2O_5 0·19, H_2O+ 0·25, H_2O- 0·06; total 100·18. Also by spectroscopic analysis NiO 0·026, Cr_2O_3 0·047 %.
16. Sim-San, Hai-nan island, south China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·90, MnO 0·11, H_2O+ 0·08; total 100·35.
17. Potao, Kwang-chow-wan, south China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·92, MnO 0·10, H_2O+ 0·07; total 100·26.
18. Samrong, 50 km. SE. of Kratié, Cambodia, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·88, Cr_2O_3 0·01, MnO 0·12, H_2O- 0·14; total 99·87.
19. Moldavite: Senohrady, Moravia. R. Nováček, 1932. Also TiO_2 0·55, MnO 0·02, H_2O+ 0·09, H_2O- 0·03; total 100·24.
20. Akakoumoekrou, Ivory Coast, West Africa. A. Lacroix, 1934, 1935. Analyst, F. Raoult; also TiO_2 0·60, MnO 0·08, H_2O+ 0·22, H_2O- 0·07; total 100·59.
21. Smach (= Schmach), Cambodia, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·99, MnO 0·10, H_2O+ 0·22; total 100·39.
22. Moldavite: Něchov, Bohemia. R. Nováček, 1932. Also TiO_2 0·36, MnO 0·07, H_2O+ 0·13, H_2O- 0·04; total 100·29.
23. Moldavite: Dukovany, Moravia. R. Nováček, 1932. Also TiO_2 0·41, MnO 0·07 H_2O- 0·03; total 99·87.
24. Moldavite: Radomilice, Bohemia. A. Lacroix, 1932. Analyst, F. Raoult; also TiO_2 0·74, MnO 0·06, H_2O+ 0·10, H_2O- 0·05; total 100·36.

35. Moldavite: Třebíč (= Trebitsch), Moravia. A. Lacroix, 1932. Analyst, F. Raoult; also TiO_2 0·72, MnO 0·09, H_2O+ 0·11, H_2O- 0·05; total 100·15.
36. Moldavite: Lhenice, Bohemia. R. Nováček, 1932. Also TiO_2 0·32, MnO 0·07, H_2O- 0·02; total 100·37.

For the specially interesting australites complete data are unfortunately lacking. The few published determinations of both specific gravity and refractive index (but without chemical analysis) made on the same sample of material are assembled in table II. These are plotted, together with the values in table I, on fig. 2. Additional determinations of d and n made on tektites from other regions are also given in table II; but, to avoid overcrowding of the diagram, these have not been plotted. Several published analyses of australites are, however, accompanied by specific gravity determinations. The silica percentages of these, together with those for a few tektites from other regions, are listed in table III (but again not plotted).

TABLE II. Specific gravity and refractive index of australites and of tektites from other regions (from the literature).

Locality.	Sp. gr.	n_{Na}.	K.	Reference.
A. Mt. William, Victoria	2·380	1·5002	0·2102	Lacroix, 1929, 1932
B. Australia	2·386	1·4981	0·2088	Ježek & Woldřich
C. Mt. William, Victoria	2·393	1·504	0·2106	Tilley
D. Hamilton, Victoria	2·415	1·5043	0·2088	Lacroix
E. Mt. William, Victoria	2·443	1·520	0·2128	Tilley
F. Australia	2·453	1·519	0·2116	Tilley
G. Charlotte Waters, Central Austr.	2·458	1·5178	0·2107	Lacroix
Other regions.				
Moldavite: Radomilice, Bohemia...	2·342	1·4879	0·2083	A. Lacroix, 1929, p. 288; 1932, p. 203. (See also table I and Ježek & Woldřich, 1910.)
„ Slavice, Moravia ...	2·345	1·4908	0·2093	
„ „ „ ...	2·345	1·4928	0·2101	
„ České Budějovice ...	2·350	1·4948	0·2106	
Hai-nan, south China	2·421	1·5065	0·2092	
Cambodia, Indo-China	2·424	1·5079	0·2095	
„	2·425	1·5092	0·2000	
Ban-Don-Phay, Cambodia ...	2·425	1·5081	0·2095	
Smach, Cambodia	2·428	1·5092	0·2097	
Cambodia, Indo-China	2·428	1·5102	0·2101	
Between Kantoum and Dek-Tô, Annam	2·438	1·5102	0·2093	
Mt. Moeriah, Java (black)	2·51	1·5241	0·2088	
„ „ (white) ...	2·512	1·5305	0·2111	

TABLE III. Silica percentage and specific gravity of australites and of tektites from other regions (from the literature).

Locality.	SiO_2.	Sp. gr.	Reference.
Uralla, New South Wales	68·91	2·459–2·482	J. C. H. Mingaye, 1916
Upper Weld, Tasmania	69·80	2·454	W. H. Twelvetrees, 1906

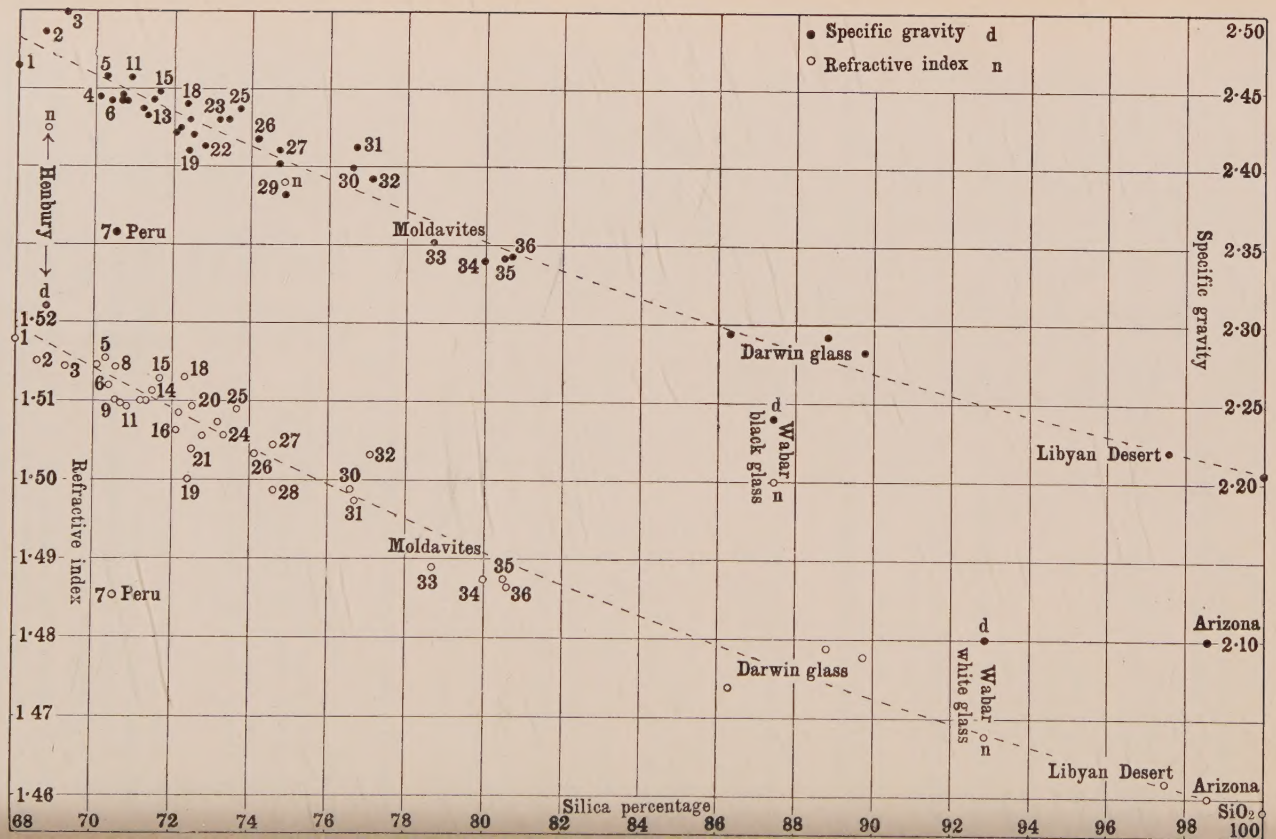
Locality.	SiO_2.	Sp. gr.	Reference.
Coolgardie, Western Australia	70·62	2·454	E. J. Dunn, 1908
Between Everard Range and Fraser Range, South Australia	71·22	2·433	F. E. Suess, 1900
Mount Elephant, Victoria	71·38	2·44	R. H. Walcott, 1898
Kalgoorlie, Western Australia	71·65	2·47	E. S. Simpson, 1902
Mount Elephant, Victoria	72·39	2·427	H. S. Summers, 1909
Central Australia	73·40	2·47	R. H. Walcott, 1898
Pieman, Tasmania	73·59	2·428	W. H. Twelvetrees, 1906
Wimmera, Victoria	73·70	2·47	Selwyn & Ulrich, 1866
Hamilton, Victoria	76·25	2·398	H. S. Summers, 1909
Charlotte Waters, Central Australia ...	76·94	2·407	J. C. H. Mingaye, 1916
,, ,, ,, ,, ...	77·15	2·395	,, ,,
Peake Station, Lake Eyre, South Australia	77·72	2·385	H. S. Summers, 1909
Other regions.			
Dendang mine, Billiton	70·30	2·4395	E. Dittler, 1933
Polo, prov. Bulacan, Philippine Islands ...	70·88	2·441–2·448	T. Hodge-Smith, 1932
Trebrung, Dendang, Billiton	70·92	2·447	F. E. Suess, 1900
Laura mine, Dendang, Billiton	71·14	2·43	R. D. M. Verbeek, 1897
Billiton, Dutch East Indies	74·30	2·503	P. van Dijk, 1879
Cetilla, Popayan, Colombia	76·37	2·310	T. Döring & O. Stutzer, 1928
Skreje, Moravia	77·78	2·3667	F. E. Suess, 1914
Kozichowitz, Trebitsch, Moravia	81·21	2·35	F. v. Hauer, 1880

Finally, in table IV are collected together a few data relating to glasses from meteorite craters and from the Libyan Desert. As seen on the plotted diagrams (figs. 1 and 2) these do not fall well in the series with the true tektites. The low specific gravity is here obviously due to the presence of bubbles in the glass, and the high refractive index of the black glass possibly to the richness in iron.

TABLE IV. Data for silica-glass from meteorite craters, Darwin glass, and from the Libyan Desert.

Locality.	SiO_2.	Sp.gr.	*n*.	*K*.
I. Black glass: Henbury, Central Australia	68·88	2·31	1·545	0·2359
II. Darwin glass: Mt. Darwin, Tasmania ...	86·34	2·296	(1·474)	(0·2065)
III. Black glass: Wabar, Arabia	87·45	2·24	1·500	0·2232
IV. Darwin glass: Mt. Darwin, Tasmania ...	88·76	2·2921	(1·479)	(0·2088)
V. ,, ,, ,, ,, ...	89·81	2·2845	(1·477)	(0·2087)
VI. ,, ,, ,, ,, ...	—	2·275	1·4790	0·2105
VII. White glass: Wabar, Arabia	92·88	2·10	1·468	0·2229
VIII. Silica-glass, Libyan Desert	97·58	2·206	1·4624	0·2094
IX. Lechatelierite: Meteor Crater, Arizona ...	(98·63)	2·10	1·460	0·2190
X. Pure silica-glass (artificial)	100	2·203	1·45845	0·2081

I, L. J. Spencer, 1933; analyst, M. H. Hey; also Fe_2O_3 8·46, FeO 7·92, &c. II, ibid.; also Fe_2O_3 0·28, FeO 5·77, &c. II, IV, V, T. W. E. David et al., 1927; the optical values are calculated from the specific refractivity of the normative


• Specific gravity d
○ Refractive index n
Specific gravity
2·50
2·45
2·40
2·35
2·30
2·25
2·20
2·10
n ○ ← Hanbury → d
1·52
1·51
1·50
1·49
1·48
1 47
1·46
Refractive index
7• Peru
Moldavites
Darwin glass
Libyan Desert
d • Wabar black glass ○ n
Arizona
7○ Peru
Moldavites
Darwin glass
d • Wabar white glass ○ n
Libyan Desert
Arizona
Silica percentage
SiO2
68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100

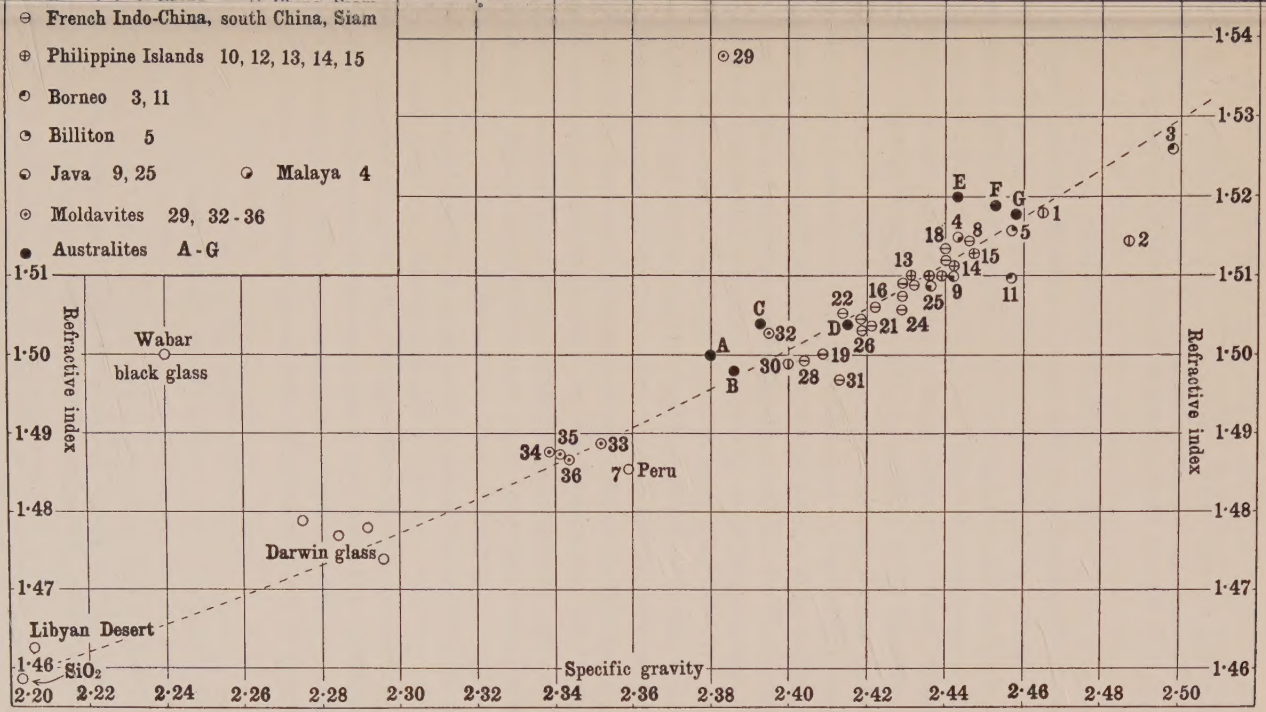


FIG. 2. Plot of specific gravity against refractive index.

Nos. 6, 16, 17, 18, 20–24, 28, 31 from French Indo-China; nos. 8, 26, 27 from south China; no. 19 from Siam. Wabar white glass and Arizona lechatelierite (with low sp. gr. due to bubbles) fall off this diagram.

minerals and the specific gravity. Direct measurements made on two other specimens gave the higher values n 1·486 and 1·497. VI, A. Lacroix, 1932, p. 203. VII, L. J. Spencer, 1933. VIII, P. A. Clayton and L. J. Spencer, 1934. IX, A. F. Rogers, 1930; silica percentage from analysis of altered sandstone, G. P. Merrill, 1907. X, R. B. Sosman, International critical tables, 1929, vol. 6, p. 341.

Darwin glass from Tasmania.

Darwin glass from the neighbourhood of Mount Darwin, near Macquarie Harbour, on the west coast of Tasmania, was described by F. E. Suess (1914, p. 98) and placed by him amongst the tektites with the special name 'queenstownite'. It is quite distinct from the tektites (australites) found at several places in the northern part of the island. More recently Suess (1933 a, p. 118; 1933 b, p. 857; 1936, p. 136; footnotes) and H. Michel (1939) have agreed that it should be classed with the silica-glass of meteorite craters. This glass is found only as small, broken, and worn fragments. It occurs abundantly ('thousands of tons', H. Conder, 1934) in glacial deposits and has evidently undergone some transportation. Much of the material is vesicular and slaggy, and has very much the appearance of the abundant silica-glass from the meteorite craters at Wabar in Arabia. Small, clear fragments are sometimes of a greenish-yellow colour, and these closely resemble the silica-glass of the Libyan Desert. David, Summers, and Ampt (1927, p. 173) mention that 'some specimens showed a number of minute black specks'. Such specimens are, however, rare, and the black specks are metallic spheres attracted by a magnet (Spencer, 1933 d). Sandstone, quartzite, and dune sands occur in the vicinity, and we can safely conclude that these 'tektites' at least were produced by the fusion of siliceous terrestrial materials in the intense heat developed when a large iron meteorite struck the earth's surface. No traces of meteorite craters or meteoritic iron have been found (nor specially searched for) at the locality; but these would be easily obliterated by glacial action, while fragments of the resistant silica-glass have survived.

Silica-glass from the Libyan Desert.

The silica-glass of the Libyan Desert differs in many respects from the tektites proper, and like them its origin presents a difficult problem. No clues have been suggested. Since Mr. P. A. Clayton's discovery of the glass in the Sand Sea in December 1932, I was privileged to join a special expedition of the Survey of Egypt to the area in December 1934. The glass was found between latitudes 25° 2′–26° 13′ N. and longitudes 25° 24′–25° 55′ E., in a more or less oval area measuring about 130 km.

J.–S. and 53 km. E.–W. The locality has since been visited and naterial collected by Mr. W. B. K. Shaw[1] in 1935 and by Major R. A. Bagnold[2] in 1938. Mr. Shaw also showed me a small, wind-worn flake f the glass with chipped surfaces which he had found inside the Gilf Kebir at 23° 2′ 4″ N., 26° 6′ 16″ E., 240 km. S. by E. of the centre of ne silica-glass area; and Mr. P. A. Clayton saw a small piece of the lass that had been collected by Count Almásy at Abu Ballas (= Pottery Hill), 24° 26½′ N., 27° 39′ E., 225 km. ESE. of the area. These isolated ieces had no doubt been transported by Arabs or prehistoric man.

An old and long-disused camel track crosses the southern end of the lica-glass area, going from the oasis of Kufara (Italian, Cufra) in yrenaica to Abu Mungar in Egypt. Here an old camel bell was found n December 1934. The former sultans of Wadia had often attempted o establish a connexion with the Nile valley. In 1810 a caravan ttempting to reach Dakhla perished of thirst. In 1846 another un-uccessful attempt was made under the leadership of one Hadji Huceyn Hussein), who related to F. Fresnel[3] that in 1846 at two or three days ut from Kufara there were seen traces of an ancient route and a great uantity of fragments of glass. P. Borchardt,[4] to whom I am indebted or this reference, has suggested that this material might have been herds of glazed pottery. No pottery of any kind was found in December 934 in the silica-glass area, but associated with the broken and flaked ieces of glass there are many quartzite implements, sandstone querns, nd broken ostrich shells. These date back long before the Egyptian ynasties; and a search with Mr. A. Lucas in the Cairo Museum of ntiquities showed none of the glass amongst the variety of ornamental tones used by the ancient Egyptians.

The accompanying map (fig. 3) and photographs (pl. xvi) will give ome idea of the peculiar configuration of the area. The parallel series f high dunes rests on an appreciably level plain of Nubian sandstone, hich is exposed in places and is then usually silicified to a quartzite. ut most of the surface in the corridors or 'streets' (2–3 km. wide) etween the dunes is covered with gravel and reddish weathered debris, r sometimes a fine white sand, and is very much like a speedway track.

[1] W. B. K. Shaw, Geogr. Journ. London, 1936, vol. 87, p. 208. M. H. Mason, he paradise of fools. London (Hodder & Stoughton), 1936, pp. 231–233.

[2] R. A. Bagnold, Geogr. Journ. London, 1939, vol. 93, pp. 286, 293.

[3] F. Fresnel, Mémoire sur le Waday. Bull. Soc. Géogr. Paris, 1850, ser. 3, vol. 13, p. 82–83.

[4] P. Borchardt, Petermanns Geogr. Mitt., 1929, vol. 75, p. 304. See also E. Behm, id., 1862, Ergänzungsheft no. 8, p. 51.

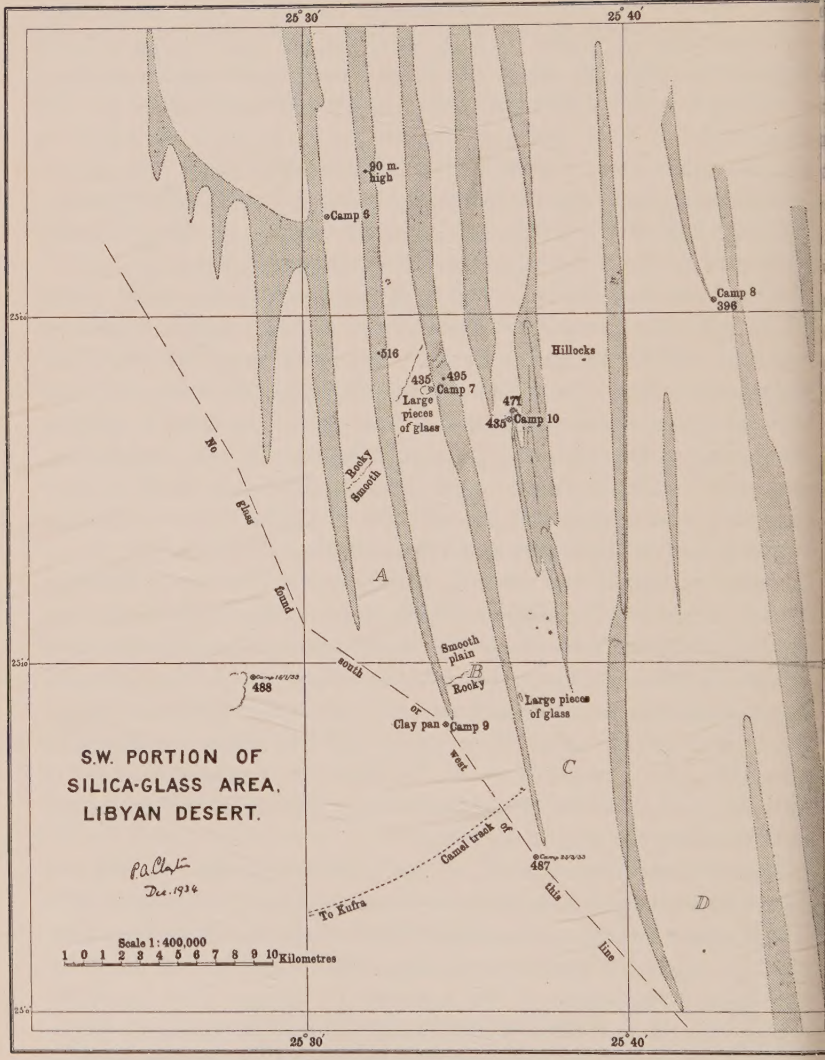


FIG. 3. Map of the SW. portion of the silica-glass area, Libyan Desert.

Reduced, with permission of the Director, from the map published in 1935 by the Survey of Egypt. Heights above sea-level in metres.

The yellow sand with rounded grains forming the dunes is not seen in the streets, and the edges of the dunes are perfectly sharp, as if tidied up with a broom. The dunes are up to 300 feet high and they extend

om north to south for more than 200 miles. Each dune, on a base
·2 km. wide, is a complex of ridges with slopes of 28° on the eastern
le and not so steep on the western side. Only one or two small pieces
the silica-glass were found on the dunes, and then in company with
one implements, suggesting that they had been transported by pre-
storic man. The glass is found in the streets, small pieces loose on
e surface and the larger pieces only partly embedded. A pit (pl. xvi,
g. 4), 2 metres in diameter, was dug near camp 7 in reddish sandy loam
own to large blocks of Nubian sandstone at a depth of 2·45 m. The
cavated material was sieved and only ten quite small pieces of glass,
ne of them flaked, were found down to a depth of 1·18 m. Small
artz pebbles and fragments of sandstone were abundant.

The glass was found most abundantly in the neighbourhood of camp 7
5° 17′ 54″ N., 25° 34′ 0″ E.) in street B. A piece weighing 6030 grams
3¼ lb.) was found 5 km. south of camp 7 and is now in the mineral
llection of the British Museum. The largest piece, weighing 7¼ kg.
6 lb.), and a clear piece of a dark green colour (5¼ kg.) were found on
e west side of street C at 8 km. from the south end of dune B–C
5° 9′ N., 25° 36′ E.) (fig. 6); these are now in the Geological Museum at
iro. Proceeding outwards from this portion of the area less and less
ass is found and the pieces are progressively smaller. The roughly oval
ea (130×53 km.) over which glass has been found reminds one of the
o areas in southern Bohemia and western Moravia in which moldavites
e found.

At several places many broken pieces of glass were found in small
atches (fig. 5); these pieces often had the form of flakes and were
ompanied by stone implements and crude 'spear-points' of glass.
ne such patch with a large stone in the centre presented quite the
ppearance of a workshop. At another spot, on an area of 2×2 yards,
1 broken fragments of glass were counted, but here no distinct flakes.
t 24 km. south of camp 8, in street D, sixty quartzite axes up to
) inches in length and of a palaeolithic type were found lying about
ith their wind-worn surfaces uppermost.

The lumps of glass are irregular in shape and range in weight from
few grams up to 7¼ kg. Smaller rounded bits are not readily dis-
nguished at sight from small pebbles and grains of clear quartz. All
them, including also flakes and worked implements, are much pitted
d wind-worn by sand blasts. Some specimens show deep conical pits
hich may pass into tubular cavities and sometimes even penetrate the
ecimen (pl. xvii, fig. 7; and Min. Mag., vol. 23, p. 507, fig. 4).

Similar cavities were seen in limestone on the Cretaceous plateau above Hez in the Bahariya oasis, where they have been formed by the whirling action of sand grains on a pitted surface, in much the same way that pot-holes are formed by pebbles under water.

The clearest pieces of the pale greenish-yellow glass contain a few minute bubbles. As these increase in number the material becomes cloudy to white and opaque in the mass. Larger bubbles are irregular in outline and up to $\frac{1}{2}$ mm. across; smaller ones (down to 1/100 mm.) are round, oval, or pear-shaped (fig. 9). A few slabby pieces show a silvery sheen on the flat surface, due to the presence of flattened bubbles up to 1 mm. across and 1/20 mm. thick (figs. 10 and 11). Several specimens show brown streaks and parallel bands in the paler coloured glass. In thin section these show as a cloud of fine dust, or at times are not at all visible. X-ray photographs of these darker portions taken by Mr. F. A. Bannister yielded only two broad bands characteristic of silica-glass.

Small ($\frac{1}{10}$–$\frac{1}{2}$, the largest 1 mm.) white spherulites are seen in many specimens, usually singly (fig. 8), but sometimes in strings and clusters. These consist of cristobalite (not quartz). They have a specific gravity of 2·35, low birefringence, and index of refraction less than that of Canada balsam, and Mr. Bannister's X-ray photograph showed the cristobalite pattern.

The results of a new chemical analysis made by Dr. M. H. Hey in 1935 on material collected by me in 1934 are given in table V, together with his earlier analysis made in 1933 on material collected by P. A. Clayton.

Table V. Chemical analysis of silica-glass from the Libyan Desert. (Analyst, M. H. Hey.)

	I.	II.	Mean.	1933.
SiO_2	97·97	98·44	98·20	97·58
TiO_2	0·21	0·25	0·23	0·21
Al_2O_3	0·91	0·49	0·70	1·54
Fe_2O_3	0·54	0·53	0·53	0·11
FeO	0·24	—	0·24	0·23
NiO	0·032	0·016	0·02	trace
MnO	—	—	—	trace
MgO	0·01	0·01	0·01	trace
CaO	0·05 ?	0·30	0·30	0·38
Na_2O	0·33	—	0·33	0·34
K_2O	0·02	—	0·02	nil
$H_2O+(110°)$ ...	0·03	—	0·03	0·05
H_2O- ...	0·03	—	0·03	0·05
Total	—	—	100·64	100·49

Spectroscopic analyses of the glass have been kindly made by several rsons to whom I had supplied material. Professor Alfred Fowler, of ondon, found Mg and an absence of Al. Professor V. M. Goldschmidt, Oslo, in work which was not completed before he left Göttingen, und no indications of impurities that might give a clue as to the igin of the material. The late Mr. Hugh Ramage, of Norwich, in the me spectrum of the 2·3 % residue [no doubt as sulphates], after ssolving the glass in HF and H_2SO_4, identified lines of Fe, weaker es of Ca, Sr, Mn, Cu, Ag, Li, Na, K, and only just visible lines of , Ni, Ga. Mr. Frank E. Chapman, on leave from the Government emical Laboratory at Perth, Western Australia, and working in the ineral Department of the British Museum, identified Mg, Cu, Al, Ba, , Fe, Pb, Mn, Ag, Si, Li, Zn, Ti, Ni, Cd in the arc spectrum of the sidue after dissolving the glass in HF and H_2SO_4. In a spectrogram the untreated glass many of the lines are masked by the large amount silica present. Dr. E. Preuss, of Jena (1935, pp. 406, 410), found $_2O_3$ 0·0006 %, and Ni if present must be less than the determinable nount of 0·001 %. This makes (with O and H) a total of 22 chemical ments found in the silica-glass from the Libyan Desert.

The red loamy sand, still adhering to larger specimens of the glass at were found partly buried, was examined by Dr. M. H. Hey, and nd to contain much calcium and magnesium carbonates, some psum, ferric oxide, and clayey material, together with rounded grains quartz with a red powdery coating. The fine white sand collected street A consists of small angular grains of quartz, $\frac{1}{4}$ mm. and less ross.

Another form of silica-glass was found at a few places in the Sand a, but this time only on the dunes. This—lightning tubes or fulgurites has the form of thin-walled tubes, glazed inside and with partly sed grains of quartz adhering to the outside. Blackened sticks pro-cting about 3 inches above the sand attracted attention because of e total absence of any vegetation. These were often surrounded on e surface of the sand by a number of broken pieces of blackened be, each also about 3 inches in length, which had evidently been oken off by the wind when sand was removed. One fulgurite was dug t to a depth of 27½ inches without reaching the end, while the broken eces found around on the surface totalled 6 feet 2 inches in length. micro-section of the glass shows it to be full of bubbles, mostly round d some elongated. The glass is isotropic and colourless with grey-own clouds and streaks.

There can be no possible connexion between this form of silica-glass found on the dunes and the lumps of glass found in the streets. A special look-out was kept for meteorites in the desert, but none was found. Any depressions (such as clay pans) were examined in the hopes that they might prove to be meteorite craters. Publication of the above notes has been delayed, now for five years, in the forlorn hope that some clue might turn up to help solve the mystery of the silica-glass of the Libyan Desert.

References.

Clayton (P. A.) and Spencer (L. J.), 1934. Silica-glass from the Libyan Desert. Min. Mag., vol. 23, pp. 501–508.

Conder (H.), 1934. Darwin glass. Industrial Australian and Mining Standard, vol. 89, pp. 329–330. [M.A. **6**–106.]

David (T. W. E.), Summers (H. S.), and Ampt (G. A.), 1927. The Tasmanian tektite—Darwin glass. Proc. Roy. Soc. Victoria, vol. 39, pp. 167–190, 1 pl. [M.A. **3**–538.]

Dijk (P. van), 1879. Obsidiaan van Billiton. Jaarb. Mijnwezen Nederl. Oost-Indië, vol. 8, pt. 2, pp. 225–230, 1 pl.

Dittler (E.), 1933. Beitrag zur chemischen Systematik der Tektite. Centr. Min., Abt. A, 1933, pp. 214–219. [M.A. **5**–304.]

Döring (T.) and Stutzer (O.), 1928. Kolumbianische Glasmeteorite. Centr. Min., Abt. A, 1928, pp. 35–41. [M.A. **5**–538.]

Dunn (E. J.), 1908. Obsidian buttons. Rec. Geol. Surv. Victoria, vol. 2, pt. 4, pp. 202–207, 2 pls.

—— 1912. Australites. Bull. Geol. Surv. Victoria, no. 27, 23 pp., 18 pls.

Hauer (F. v.), 1880. Bouteillenstein von Trebitsch. Verhandl. Geol. Reichsanst. Wien, 1880, pp. 282–284.

Heide (F.), 1938 a. Über Tektite von den Philippinen. Zentr. Min., Abt. A, 1938, pp. 289–293. [M.A. **7**–276.]

—— 1938 b. Über Tektite von Siam. Ibid., 1938, pp. 359–360. [M.A. **7**–276.]

—— 1939. Über Tektite von Java. Ibid., 1939, pp. 199–206. [M.A. **7**–381.]

Hills (L.), 1915. Darwin glass, a new variety of tektites. Rec. Geol. Surv. Tasmania, no. 3, 14 pp., 4 pls. [M.A. **1**–407.]

Hodge-Smith (T.), 1932. Obsidianites in the Philippine Islands. Philippine Journ. Sci., vol. 48, pp. 581–587. [M.A. **5**–160.]

Ježek (B.) and Woldřich (J.), 1910. Příspěvek k řešení otázky tektitové. Rozpravy České Akad., Ser. II, vol. 19, no. 30, 12 pp. 1 pl. Beitrag zur Lösung der Tektitfrage. Bull. Internat. Acad. Sci. Bohême, vol. 15, pp. 232–245, 1 pl.

Koomans (C. M.), 1938. On tektites and pseudo-tektites from Dutch East Indies and Philippines. Leidsche Geol. Meded., vol. 10, pp. 63–81. [M.A. **7** 275.]

Lacroix (A.), 1929. Sur la composition chimique des tectites, et en particulier de celles du Cambodge. Compt. Rend. Acad. Sci. Paris, vol. 188, pp. 284–288. [M.A. **4**–122.]

—— 1930. Nouvelles observations sur les tectites de l'Indochine. Ibid., vol. 191, pp. 893–899. [M.A. **5**–18.]

—— 1931. Les tectites des Philippines. Ibid., vol. 193, pp. 265–267. [M.A. **5**–18.]

—— 1932. Les tectites de l'Indochine. Arch. Mus. Hist. Nat. Paris, ser. 6, vol. 8, pp. 139–240, 12 pls. [M.A. **5**–303.]

ACROIX (A.), 1934. Sur la découverte de tectites à la Côte d'Ivoire. Compt. Rend. Acad. Sci. Paris, vol. 199, pp. 1539–1542. [M.A. 6–106.]
— 1935. Les tectites de l'Indochine et de ses abords et celles de la Côte d'Ivoire. Arch. Mus. Hist. Nat. Paris, ser. 6, vol. 12, pp. 151–170, 4 pls. [M.A. 6–209.]
NCK (G.), 1926. Ein neuer kristallführender Tektit von Paucartambo in Peru. Chem. Erde, vol. 2, pp. 157–174, 1 pl. [M.A. 3–97.]
— 1928. Oberfläche und Herkunft der meteorischen Gläser (Tektite). Neues Jahrb. Min., Abt. A, Beil.-Bd. 57, pp. 223–236, 1 pl. [M.A. 3–539.]
ERRILL (G. P.), 1907. On a peculiar form of metamorphism in siliceous sandstone. Proc. U.S. Nat. Mus., vol. 32, pp. 547–550, 1 pl.
ICHEL (H.), 1939. Tektite. Fortschr. Min. Krist. Petr., vol. 23, pp. cxliii–cxlv. [M.A. 7–380.]
INGAYE (J. C. H.), 1916. Analyses of obsidianites from Uralla district and Charlotte Waters. Rec. Geol. Surv. New South Wales, vol. 9, pp. 170–171, 1 pl. [M.A. 1–409.]
UELLER (F. P.), 1915. Tektites from British Borneo. Geol. Mag. London, dec. 6, vol. 2, pp. 206–211. [M.A. 1–407.]
OVÁČEK (R.), 1932. Analysy čtyř vltavínů českých a moravských. [Analyses of four Bohemian and Moravian moldavites.] Časopis Národního Musea, Praha, vol. 106, p. 68. [M.A. 5–161.]
EUSS (E.), 1935. Spektralanalytische Untersuchung der Tektite. Chem. Erde, vol. 9, pp. 365–418, 2 pls. [M.A. 6–108.]
GERS (A. F.), 1930. A unique occurrence of lechatelierite or silica glass. Amer. Journ. Sci., ser. 5, vol. 19, pp. 195–202. [M.A. 5–16.]
AWYN (A. R. C.) and ULRICH (G. H. F.), 1866. Notes sur la géographie physique, la géologie, et la minéralogie de Victoria. Exposition Intercoloniale, Melbourne. (Analysis by C. Newbery on p. 97.)
MPSON (E. S.), 1902. Obsidianites. Bull. Geol. Surv. Western Australia, no. 6, pp. 79–85, 3 pls.
ENCER (L. J.), 1933 a. Meteoric iron and silica-glass from the meteorite craters of Henbury (Central Australia) and Wabar (Arabia). Min. Mag., vol. 23, pp. 387–404.
— 1933 b. Origin of tektites. Nature, London, vol. 131, pp. 117–118. [M.A. 5–304.]
— 1933 c. L'origine des tectites. Compt. Rend. Acad. Sci. Paris, vol. 196, pp. 710–712. [M.A. 5–304.]
— 1933 d. Origin of tektites. Nature, London, vol. 132, p. 571. [M.A. 5–407.]
— 1936 a. The tektite problem. Popular Astronomy, Northfield, Minnesota, vol. 44, pp. 381–383. Min. Mag., 1937, vol. 24, pp. 503–506.
— 1936 b. A key to precious stones. London and Glasgow (Blackie). Silica glass, pp. 205–208, 1 pl.
ESS (F. E.), 1900. Die Herkunft der Moldavite und verwandter Gläser. Jahrb. Geol. Reichsanst. Wien, vol. 50, pp. 193–382, 8 pls.
— 1914. Rückschau und Neueres über die Tektitfrage. Mitt. Geol. Gesell. Wien., vol. 7, pp. 51–121, 3 pls.
— 1933 a. Zur Beleuchtung des Meteoritenproblems. (Mit Bezug auf das durch A. Lacroix erschlossene indo-chinesische Tektitgebiet.) Mitt. Geol. Gesell. Wien, vol. 25 (for 1932), pp. 115–143. [M.A. 5–406.]
— 1933 b. Wie gestaltet sich das Gesamtproblem der Meteoriten durch die Einreihung der Tektite unter die meteoritischen Körper. Naturwissenschaften, vol. 21, pp. 857–861. [M.A. 5–406.]

Suess (F. E.), 1936. Der Meteor-Krater von Köfels bei Umhausen im Ötztale, Tirol. Neues Jahrb. Min., Abt. A, Beil.-Bd. 72, pp. 98–155, 4 pls. [M.A. 6–401.]

Summers (H. S.), 1909. Obsidianites—their origin from a chemical standpoint. Proc. Roy. Soc. Victoria, new ser., vol. 21, pp. 423–443.

Tilley (C. E.), 1922. Density, refractivity, and composition relations of some natural glasses. Min. Mag., vol. 19, pp. 275–294.

Twelvetrees (W. H.), 1906. Record of obsidianites, or obsidian buttons, in Tasmania. Rep. Secretary Mines, Tasmania, for 1905. pp. 60–66. The chemical analyses by W. F. Hillebrand are repeated in Bull. U.S. Geol. Surv., 1910, no. 419, p. 181.

Verbeek (R. D. M.). Glaskogels van Billiton. Jaarb. Mijnwezen Nederl. Oost-Indië, 1897, vol. 26, pp. 235–272, 1 pl.

Walcott (R. H.), 1898. The occurrence of so-called obsidian bombs in Australia. Proc. Roy. Soc. Victoria, new ser., vol. 11, pp. 23–53.

Explanation of Plates XVI and XVII.

Silica-glass from the Libyan Desert.

(Photographs (figs. 4–6) by L. J. Spencer; photomicrographs (figs. 8–11) by D. L. Williams, Mineral Department, British Museum.)

Figs. 1–3 in the text.

Plate XVI, Fig. 4. Pit dug to bed-rock at camp 7, street B. Dune B–C in the distance.

Fig. 5. Lumps and broken flakes of silica-glass (white), with darker sandstone fragments. Near camp 7, street B.

Fig. 6. Silica-glass and quartzite flakes collected on the west side of street C, 8 km. from the south end of dune B–C.

Plate XVII, Fig. 7. Silica-glass showing tubular cavities with conical end (rod projecting from one). An old break in the direction of the tubes shows the inside of the tubes with a different type of erosion. B.M. 1935,83. $\times \frac{4}{5}$.

Fig. 8. Spherulites of cristobalite in clear glass. B.M. 1935,141. $\times 16$.

Fig. 9. Abundance of bubbles in cloudy glass, opaque white in the mass. B.M. 1935,145. $\times 16$.

Fig. 10. Flat bubbles in white translucent glass with silvery sheen on slabby surface. Section parallel to this surface. B.M. 1935,147. $\times 16$.

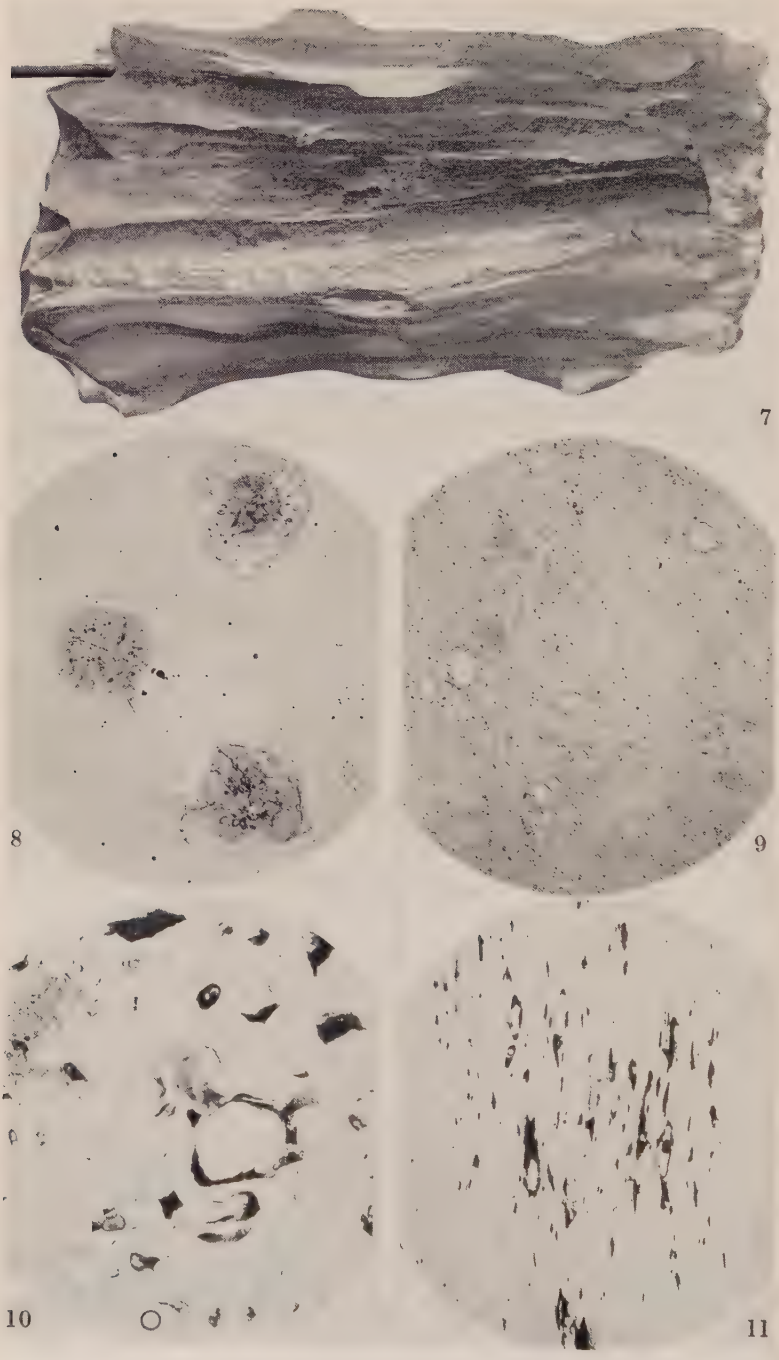
Fig. 11. Ditto. Section perpendicular to this surface. B.M. 1935,147. $\times 16$.

4

5

6

L. J. Spencer: Silica-glass from the Libyan Desert.



L. J. Spencer: Silica-glass from the Libyan Desert.

On the relation of chamosite and daphnite to the chlorite group.[1]

(With Plates XVIII and XIX.)

By A. F. Hallimond, M.A., Sc.D.
Assistant Curator, Museum of Practical Geology, London.

With chemical analyses by C. O. Harvey, B.Sc., A.R.C.S.
and X-ray measurements by F. A. Bannister, M.A.

[Read June 9, 1938.]

I. Introduction.

THERE is a close optical and chemical resemblance between chamosite, the chloritic mineral of the bedded ironstones, and daphnite, low-temperature vein-chlorite common in some of the Cornish tin mines. New material has made it possible to undertake a fresh comparison of the two minerals: chemical analyses have been made by Mr. C. O. Harvey, chemist to H.M. Geological Survey, and a report on the X-ray measurements is contributed by Mr. F. A. Bannister, of the Mineral Department of the British Museum.

The new analysis of chamosite agrees with the simple formula previously assigned: X-ray examination of material from several localities has now established the distinctive crystalline nature of this fine-grained mineral, which differs structurally from ordinary chlorites such as clinochlore. Daphnite, on the other hand, has the ordinary chlorite structure, but the new analysis fully confirms Tschermak's original opinion that it cannot be represented chemically as a mixture of serpentine and amesite.

In attempting a comparison with chlorite analyses already published, great difficulty arises from the confused nomenclature. In order to ascertain the nearest chemically allied chlorites to those under discussion, a representative number of selected chlorite analyses have been plotted on a diagram with co-ordinates proportional to R_2O_3/SiO_2 and FeO/SiO_2. This diagram illustrates clearly the relation of the several chlorites here mentioned to other similar minerals and to the formulae that have been proposed.

[1] Published by permission of the Director, Geological Survey and Museum.

As a result of the X-ray measurements it is found that the iron-ore chlorite, bavalite, is an orthochlorite resulting from the recrystallization of chamosite in an early stage of metamorphism.

II. Daphnite from the Tolgus mine, Cornwall.

The name daphnite was given by Tschermak (1891, p. 74) to material 'from Penzance' obtained in 1840. An analysis by R. Zeynek showed that the mineral was predominantly an iron-chlorite with low magnesia, and that its composition lay outside the main serpentine-amesite (Sp–At) series. Tschermak accordingly represented the composition by $At'_5At_5Sp_4$ (At' being $SiAl_2H_2O_7.MgOH.H$), and classed it in his leptochlorite division.

Several iron-chlorites have since been described under the name daphnite, which has been proposed by A. N. Winchell (1936, p. 649) as a varietal name to be used for a range of optically negative chlorites with high refractive index and negative birefringence (corresponding with a high iron content). The rest of the chlorite group was similarly divided by Winchell into varieties arbitrarily based on the optical properties. Although this procedure offers a convenient means of supplying a name for any chlorite, it will be evident (for example in the present case) that some chloritic minerals which are structurally different are too closely alike for it to be an adequate means of classification.

The original daphnite was a scaly vein-chlorite encrusting quartz and arsenopyrite. A specimen of similar chlorite from New Rosewarne mine (M.I. 3211x), cementing broken quartz and clay-slate, was purchased by the Museum of Practical Geology in 1873. Scaly iron-chlorite occurs in large quantities in many of the Cornish lodes, but has generally been termed simply chlorite. The specimen now to be described is typical of this vein-material. It was presented to the Museum (M.I. 16006) by Mr. R. H. Porter, and was obtained during the sinking of a new shaft at Tolgus mine, near Redruth, in 1926; it occurred in a vein penetrating killas, at a depth of about 1450 feet below the surface.

Daphnite (M.I. 16006).—Vein-stuff with one side attached to green chloritic killas. The vein-fissure contains prisms of milky quartz up to $1\frac{1}{2}$ inches in length; the interstices between these are filled with scaly, dark green chlorite, which forms coatings on the quartz about $\frac{1}{8}$ inch thick, composed of fan-like aggregates with their cleavage roughly normal to the quartz surface. The laminae are soft and flexible. Micro-section, E 13984, cut from the preceding (pl. xviii, fig. 1). The chloritic coatings are composed of fan-like tufts, with radial extinction. In a few

ases the outer ends extend as thin tabular crystals with no measurable xternal form, embedded in a later filling of vein-quartz. The chlorite is nsibly uniaxial, negative, with birefringence equal to that of the ssociated quartz (0·009). Pleochroic: ω green, ϵ pale greenish-yellow. etween the vein and the killas is a layer of earlier granular vein- aterial, composed of sutured quartz and orthoclase, with nests of hlorite, prisms of brown tourmaline, and white mica, sometimes hloritized.

The green coatings were readily separated by hand and broken up r analysis, yielding a flaky powder. The separated mineral was nalysed by C. O. Harvey by the usual methods, with slight modifica- n on account of the rather small quantity. The results are shown elow, with earlier analyses for comparison.

TABLE I. Analyses of daphnite.

nalyst ...	...C. O. Harvey*	R. Zeynek (Tschermak, 1891)	E. S. Simpson (1936)	E. S. Simpson (1937)
ocality ...	... Tolgus mine, Cornwall.	'Penzance', Cornwall.	Randalls, W. Australia.	Kalgoorlie, W. Australia.
$O)_2$	24·35	23·62	23·43	23·32
$_2O_3$	20·21	22·26	18·21	17·45
O_2	0·04	—	—	0·03
$_2O_3$	2·13	nil†	4·49	4·09
O	36·27	38·97	36·30	38·90
nO	0·48	0·98	trace	0·01
gO	5·57	1·09	5·41	4·54
O	0·10	0·29	nil	0·24
$_2O$	n.d.	1·10	nil	nil
$_2O$	n.d.	0·28	nil	trace
$_2O >$ 105° C. ...	10·46	11·16	12·15	10·89
$_2O <$ 105° C. ...	0·35		trace	0·80
tal	99·96	99·75	99·99	100·27
. gr.	3·08	3·172	3·14	3·10
fr. index ω (D)	1·655	—	1·661	1·662
fr. index ϵ (D)	1·646	—	1·656	1·659

* Geol. Survey, Lab. no. 1020.

† 'Enthält kein Eisenoxyd' (Tschermak, 1891, p. 69).

These analyses are plotted in fig. 1: nos. recent 14, Orcel 132, and cent 18 and 16, respectively.

III. CHAMOSITE FROM FRODINGHAM, LINCOLNSHIRE.

The Frodingham ironstone is a shelly limestone alternating with bands her in clay. It contains abundant limonite ooliths, but the clayey oundmass approximates in composition to a chalybite-chamosite mud-

stone, consisting of minute rhombohedra of chalybite in a weakly birefringent matrix of chamosite and clay.

Shells of *Gryphaea* are common in the ironstone; the specimen now described (pl. XVIII, fig. 3) was presented by Mr. J. Behrendt many years ago, as representative of a curious green filling sometimes found in these shells. The shell was evidently intact when found, with the valves closed; it had been split open, the valves separating readily as shown, to reveal a smooth olive-green mass which is a cast of the interior of the shell. The green material resembles the groundmass of the ironstone outside the shell, but is almost free from ooliths and other coarser particles: evidently a slow infiltration has taken place while the dead shell was being enclosed in the ironstone, in such a way that the heavier particles were prevented almost completely from entering the cavity. The smooth green material in this case contains rather a large proportion of chalybite as minute rhombohedra.

Another shell of the same kind was collected by the writer at Frodingham (pl. XVIII, fig. 4). It is incompletely filled with the dark green paste, which occupies what was possibly the lower half of the shell. The remaining space has been filled with comby vein-calcite which is no doubt the cementing calcite of the limestone. The shell is imperfect in shape, as if it had been injured, possibly during life, but it forms a nearly complete enclosure. A microsection (pl. XVIII, fig. 2) shows clearly the rounded irregular surface of the green paste. The green mineral forms distinct granules suggesting a flocculent colloid or chemical growth. There is a rather striking resemblance to structures much discussed in reference to greenalite and glauconite: the cauliflower-like granules are embedded in calcite or closely aggregated. In bulk the mineral is almost isotropic, with scattered minute black specks, and a few pleochroic birefringent flakes (of chlorite); under the highest magnification it appears at the edges to be a felted mass of very minute flakes. Where quite free from staining, the colour is a clear jade-green. Chalybite crystals are present in places as groups of elongated rhombohedra, which are evidently of late origin, replacing the vein-calcite; they are somewhat stained by oxidation, and there is also a slight staining of the chlorite, but the latter has been chemically protected by the more readily oxidizable carbonate (Hallimond, 1925, p. 107).

Clastic particles, such as quartz or limonite grains, are absent; the flocculent aggregates would seem to represent a chemical precipitation of nearly pure chlorite. It was decided to sacrifice the greater part of the material in order to obtain an analysis, and the soft paste was removed

rom the shell-cavity with a sharp steel point. Inevitably it was ac-
ompanied by small amounts of calcite and chalybite, but, as remarked
bove, these carbonates are of quite extraneous origin, and should be
educted from the analysis. The stained part of the material was not
sed.

The refractive index (by immersion) of the analysed material in
odium-light was approximately 1·665. By weighing in distilled water
a pyknometer the density was found to be 3·242. This includes
rbonates, &c., and after correction for calcite, chalybite, and clay, as
own by the analysis below, the calculated density of the chlorite is
·34; this may be a little high if the residual clay contains iron.

The chlorite was analysed by C. O. Harvey by extraction with *N*/2-HCl
cording to the method described by F. R. Ennos and R. Sutcliffe (in
allimond, 1925). The revised electrometric method (Sutcliffe) was not
sed. On account of the small amount of material the methods were
apted to a semi-micro scale. Adequate precautions were taken, but
yond this no special description seems necessary. The semi-micro
termination of carbon dioxide was not carried out until a satisfactory
ntrol result had been obtained with a splinter of pure calcite; this
ntained theoretically 0·00733 gm. CO_2, and the figure obtained was
·00730 gm.

TABLE II. Analyses of chamosite and bavalite.

nalyst	...	C. O. Harvey*		H. Jung (1931)	V. V. Chernykh (1926)	J. Orcel (1927, p. 246)	H. Jung (1930)
ocality	...	Frodingham, Lincolnshire.		Schmiedefeld, Thuringia.	Hayanges, Lorraine.	Bas Vallon, Brittany.	Schmiedefeld, Thuringia.
O_2	...	19·77	24·9	26·65	25·04	22·27	20·82
O_3	...	—	—	trace	—	0·08	trace
$_2O_3$	...	12·40	15·6	16·14	20·10	21·40	17·64
$_2O_3$	...	5·74	7·2	6·69	2·05	0·67	8·70
O	...	31·02	35·0	34·43	35·40	43·01	37·96	
O)	...	0·35	0·4	—	—	0·05	—
gO	...	3·63	4·6	4·47	4·28	2·35	4·15
O	...	3·34	—	—	—	0·15	—
O_5	...	0·26	—	—	—	—	—
$_2O_3$	...	0·32	—	—	—	—	—
$_2$	...	4·22	—	—	—	—	—
O+	...	—	(12·3)	11·42	} 12·87	10·10	10·31
O—	...	—	—	0·08		0·11	0·07
sol.	...	7·8	—	—	—	—	—
tal	...	(88·85)	100·0	99·88	99·74	100·54†	99·65
. gr.	...	—	3·34	3·19	—	—	—

* Geol. Survey, Lab. no. 1015. The second column gives the Frodingham analysis after deducting
bonates, &c., and recalculating to 100, assuming 12·3 % H_2O.
† Including alkalis 0·35.

From the above analysis the calculated mineral composition of the
rodingham material is as follows:

$Ca_3(PO_4)_2$	...	...	...	0·57	Remaining oxides.	Molecular ratios.
$CaSO_4$ ...	...	...	...	0·54	SiO_2 19·77	200
$CaCO_3$ ...	...	...	...	5·01	Al_2O_3 12·40	96
$FeCO_3$ ...	...	...	...	5·26	Fe_2O_3 5·74	
				11·38	(Fe,Mn)O 28·11	292
					MgO 3·63	
					69·65	

Total remaining oxides (69·65) correspond to 79·39 % of chamosite containing 12·3 % H_2O. The figure for 'insoluble' is approximate, owing to deflocculation difficulties during washing. The original material contained 1·3 % H_2O < 105° C., 8·9 % H_2O > 105° C. FeO may be slightly higher than the true value owing to presence of organic matter. The molecular proportions given above for the 'residual oxides' agree, within the limits of error in an analysis of this kind, sufficiently closely with the simple formula $2SiO_2.R_2O_3.3RO.aq$.

Analyses of chamosite from Schmiedefeld and Hayanges are given for comparison. Apparently the ferric iron substitutes part of the alumina. The last two analyses, of bavalite from Bas Vallon and 'thuringite' from Schmiedefeld, represent alteration products due to the incipient metamorphism of chamositic ironstones. They are characterized by lower SiO_2 and higher RO than the chamosites; both have orthochlorite composition (see section VII).

IV. Earlier Analyses of Chamosite.

Analyses by acid extraction.—Chamosite, though present in very large amounts in bedded iron-ores, has never been found in the pure state. It is invariably fine-grained, though sparse crystalline flakes in the ironstones have been provisionally regarded as chamosite. Alteration to chalybite and clay is extremely common, and the clay, which may be pseudomorphous after the chamosite, is so closely intergrown that there is little prospect of separating the two minerals by mechanical means, nor can they be distinguished with certainty under the microscope. Thus there seems to be no direct physical means of measuring the proportion of chamosite present, even when it forms the bulk of the rock. Fortunately a chemical method has served to distinguish the mineral. Unaltered chamosite is remarkably soluble in hot, very dilute ($N/2$) hydrochloric acid, while the clay constituent of the ironstones is almost insoluble. A standard method of acid extraction was developed by F. R. Ennos and R. Sutcliffe (in Hallimond, 1925). It was later successfully employed by T. Deans (1934 a) and has been used by Mr. C. O. Harvey in the present analysis and in other Survey analyses of chamo-

tic rocks to be described below. Sutcliffe found that the peculiar lubility was confined to the unaltered ironstones; those from Wales, hich have suffered some slight degree of recrystallization, dissolved ore slowly and were difficult to filter (see later, on the alteration of amosite). In the English unaltered ironstones the extract was fairly ose to the simple chamosite composition, as will be seen from the llowing table, which gives the percentage of soluble chloritic oxides esent and their molecular ratios.

TABLE III. Chamosite in British ironstones. Molecular proportions by acid extraction ($SiO_2 = 200$).

	% soluble oxides, or chamosite.	R_2O_3.	RO.
. Frodingham ('sulphur bed')	21·91	99	282
. ,, ('top bed')	16·05	110	296
. ,, (Lias clay)	13·11	87	318
. Cleveland ('dogger stone')	12·77	108	329
. ,, (Pecten seam)	46·21	107	303
. ,, (shale)	22·72	100	283
. Marlstone (green ore)	39·94	100	301
. * ,, pebble (phosphatic)	48·61	152	299
. *Westbury (? oxidized)	25·91	129	245
. *Northants. (? oxidized)	17·45	152	239
Yorkshire (T. Deans, 1934 a, p. 58) ...	'70·55 % cham.'	115	290
. *Ayrshire clay (B. E. Dixon, 1930, no. 874)	78·45	154	296
.. ,, (,, ,, no. 875)	24·67	119	303
Omitting four analyses marked * ...	highest	119	329
	lowest	87	282

The first ten analyses are by F. Ennos and R. Sutcliffe (in Hallimond, 1925). part from the four marked * these values agree fairly well with the simple ratio R_2O_3 : 300 RO.

Freshwater chamosite.—Chamosite is commonly a marine mineral; in ie Coal Measures the chalybite mudstones form a special class of iron- re from which chamosite is absent (Hallimond, 1925, p. 62). T. Deans 934 a, p. 58), however, has described an exceptional bed from the orkshire Coal Measures, containing 70·55 % of chamosite; this rock parently formed under conditions involving the reversible reaction etween clay, chalybite, and chamosite. Other exceptional occurrences ave been recorded from localities in Ayrshire: V. A. Eyles (1930, p. 67) escribes green clays from Borland which resemble chamosite in bulk mposition (Lab. no. 424) and which have been formed by the decom- osition of Millstone Grit lavas. Similar clays are also discussed by . V. Wilson (1930, p. 209), who regards them as freshwater lagoon-

deposits that have been covered by thick vegetation; they contain sphaerosiderite, kaolinite, bauxitic alumina, and the chloritic mineral, and show oolitic structures which he regards as originally formed of aluminium hydroxide. Indeed, the high proportion of alumina has given a commercial value to one bed, the Ayrshire bauxitic clay (Wilson, 1922). Kaolinite and the chlorite are often of secondary formation, which is attributed to the action of acids under the thick cover of vegetation (see also T. Deans, 1934 b); indeed, the whole mineral assemblage suggests a balance of products formed from the iron-bearing lavas by the continued action of circulating waters. These rocks have a good deal in common with those from Yorkshire, but the latter apparently owe their iron content to ordinary Coal Measures sedimentation, for there are no associated lavas. The green mineral is present in large amounts in some of the Ayrshire rocks; two analyses by acid extraction were made by B. E. Dixon (1930, p. 98) with the results shown in table III (12 and 13). The high proportion of soluble alumina in no. 874 is attributed to the soluble bauxitic alumina often present in this series of rocks; with this allowance, both analyses agree in composition with the simple ratios assigned to chamosite.

Another example of chloritic silicate from Ayrshire has been found in the Coal Measures (details communicated by Mr. V. A. Eyles). The rock occurs in a railway cutting a few yards north of the Ayr–Whitletts road. A micro-section, S 22520, shows minute rhombohedra and groups of chalybite sprinkled in a pale green chloritic groundmass which is composed of felted, weakly birefringent flakes, with positive elongation and pleochroism pale green to colourless.

Dehydration.—H. Jung (1931) has given a very careful account of the composition and dehydration of chamosite from Schmiedefeld. This was prepared by finely powdering the ore and separating the chalybite and magnetite by flotation in Clerici solution of density 3·55. After several days the small floating portion was recovered, washed, and further cleaned with warm dilute acetic acid. The analysis (table II) shows a rather higher percentage of silica than is required by the simple formula, but the treatment outlined above seems liable to give rise to such a result, either by the failure to remove silica disseminated in the rock, or by alteration of the fine powder during prolonged separation. A well-defined dehydration curve was obtained with the Hüttig tensieudiometer. The curve was similar to those for thuringite and kaolinite, nearly all the water being lost sharply at about 420° C. if the vacuum was maintained for a sufficient time; the loss began, however, at 390°.

Chernykh's results (1926) on chamosite from Hayanges near Metz form part of a general study of chlorites, &c. Thermal curves were obtained by fairly rapid heating, showing several rather blunt 'delays' between 280 and 1000° C.; there is, however, very little feature near the 420° point for chamosite, the 'leptochlorite' delay being at 620° for chamosite and thuringite. Two grams of material were heated in the short time of half an hour (details of method for brucite, Chernykh, op. cit., p. 82). Jung (above) found that by successive removal of water vapour as the pressure rose to 3·0 mm., the dehydration at 420° was only completed after several intervals of $\frac{1}{2}$–2 hours. It seems likely, therefore, that the higher temperatures recorded by Chernykh relate to the evolution of water under, at least, atmospheric pressure and are less exact.

Differential thermal analyses are also recorded by Orcel (1927), with a summary of earlier work. Here again the rate of heating (9 degrees per minute) is sufficiently rapid to incur the risk of delay in view of the slow dehydration observed by Jung. Bavalite (no. 128) gave two peaks (endothermic) beginning near 470° and 530°. 'Aphrosiderite' (no. 123) and 'thuringite' (no. 25) also gave peaks at 500°, but the other chlorites decomposed at about 600° C. Other measurements were made by heating the chlorite in an exhausted enclosure and measuring the change of pressure with temperature. In this case the first evolution takes place under low pressure; by very slow heating, sharp inflexion points were obtained. The first inflexion temperatures were: aphrosiderite (no. 123) 420–440°; bavalite (no. 128) 440° very sharp; 'thuringite' (no. 13, Messina, Transvaal) 440–450°. These minerals showed a further loss beginning about 550° C., but the pressure had been allowed to rise at the end of the first dehydration to about 20 mm. The other chlorites decomposed at 500° or over, with a second evolution at 620–720°. Orcel's first rough measurements thus correspond with those of Chernykh, but the temperatures are lower, while the later measurements, 420–440°, are in close accord with 420° observed by Jung for chamosite.

By these dehydration experiments the distinctive behaviour of the 'leptochlorites' seems well established, but it is not clear whether their low decomposition temperature is due chiefly to the substitution of iron for magnesia or to structural difference. It will be shown in Mr. Bannister's report that chamosite has a different structure from bavalite (Orcel, no. 128), which is an orthochlorite, so that the iron content may be the important factor.

V. Graphical Representation of the Chlorites.

It is helpful to have some means of selecting those chlorite analyses that approximate to a given composition. For this purpose the nomenclature is so confused as to be useless, but it is possible to construct a diagram resembling that for the biotite group (Hallimond, 1926, p. 29) which will indicate chemically similar analyses regardless of theoretical considerations, and which may be used to test the extent to which the analyses agree with theory. The use of graphs is suggested by Orcel (1927, p. 412), though his parameters are unsuitable for plotting, and the analyses here plotted (fig. 1) are taken chiefly from his monograph, which gives a very complete survey of analyses up to 1927.

During recent years, since the announcement of the chlorite cell formulae obtained by X-ray methods, it has been usual to give the atomic ratios for (O,OH) = 18 in publishing new analyses. For a representation dealing only with analyses referable to the same cell-formula there is no doubt that a special plotting, using the variables of the cell-formula, would be of great interest. But for the general comparison of a series of analysed minerals which may not be isostructural, e.g. of the orthochlorites with stilpnomelane, chamosite, &c., and for the general relations of the chlorites as a part of the oxide system (phase rule) such a plotting cannot be used. For the purpose of the present investigation, therefore, the plotting of fig. 1, in terms of the component (grouped) oxides, RO, R_2O_3, SiO_2, was used.

By selecting the points nearest to that representing a new analysis it is possible to obtain a complete account of earlier similar analyses, regardless of nomenclature. This is easier than the selection of analyses with similar ratios in the Orcel tables, since his narrow sections (fig. 1) result in a highly artificial sub-division, which means that similar analyses occur in different sections and are liable to be overlooked.

Choice of parameters.—Practically all chemical theories accept as a common basis the mutual replacement of $(Fe,Al,Cr)_2O_3$ and of (Fe,Mg,Mn)O (cf. Orcel, p. 324); the grouped oxides being written respectively R_2O_3 and RO. Calcium and the alkalis are usually absent from the chlorites, so that any member of the chlorite group (in the broad sense) can be represented in terms of the constituents SiO_2, R_2O_3, RO, and H_2O. So far as the 'solid' constituents are concerned, therefore, the chlorites can be represented by points on a plane diagram with co-ordinates proportional to the two variables R_2O_3/SiO_2 and RO/SiO_2. It is convenient, in discussing chamosite, to plot the values

R_2O_3 and RO when $SiO_2 = 200$, but the diagram could be adapted to any other value for SiO_2 by re-scaling the co-ordinate axes.

If the chlorites formed a single isomorphous series, this diagram might serve to determine the position of any new analysis in relation to the rest of the group, but it is certain that besides the main chlorite group there are several non-isomorphous chloritic minerals, of which chamosite is an example, possibly also amesite and cronstedtite (see report on X-ray data); these also, when plotted, appear in the diagram and may sometimes coincide in composition with chlorites of the main series; additional tests, especially by X-ray and solubility, are therefore essential for complete identification. Nevertheless, the graph gives an interesting comparative view of the chlorite group.

Selection of analyses for plotting.—Orcel's tables contain 262 numbered analyses (omitting those with chromium). Many, however, are early or incomplete, so that a careful selection must be made. In the first place, all results dated before 1890 were omitted: this inevitably excludes a few good analyses, but a large number are eliminated that are certainly inaccurate. Next a certain number were omitted which showed important amounts of CaO or alkalis. The latter may in some cases represent true minerals, but they are rare and would be best studied separately. Even after this elimination, 79 analyses remained to be plotted.

Co-ordinates.—The ratios given by Orcel, $s = SiO_2/R_2O_3$, $a = Fe_2O_3/Al_2O_3$, and $f = FeO/MgO$, are not suitable for the present method of plotting. Values for the co-ordinates here used, namely 200 R_2O_3/SiO_2 and 200 RO/SiO_2, were therefore calculated from the molecular ratios stated by Orcel in the column following each analysis. As an example: amesite, no. 2 (Orcel, p. 331), has the equivalents SiO_2 347, R_2O_3 344, RO 692; when $SiO_2 = 200$ these become R_2O_3 198, RO 399, the co-ordinates of point 'Orcel 2' in fig. 1.

Recently published chlorite analyses can readily be plotted on this diagram, and the nearest existing analyses ascertained. No attempt has been made to include all the later chlorites which fall within the crowded area, but many recent daphnites have been added and are numbered as in table IV. Some less accurate chamosites extracted from sedimentary rocks by acid are given only in fig. 2.

VI. Chemical Relationship of Chamosite and Daphnite to the Chlorite Group.

Fig. 1 represents the main group of known chlorite analyses. Stilpnomelane and some delessites lie to the left of the area shown. Tschermak,

TABLE IV. Recent data for chamosite &c. ($SiO_2 = 200$).
The numbers refer to points on figs. 1 or 2.

		R_2O_3.	RO.	100 FeO/FeO+MgO.
Chamosite:				
1–7.	The first seven in table III (acid extraction)	—	—	—
8.	Harvey (p. 445). Frodingham	96	292	—
9.	Jung, 1931. Schmiedefeld	92	271	81
10.	Chernykh, 1926. Hayanges	100	287	82
11.	Radley, 1920. Raasay	87	256	82
12.	Deans, 1934. Yorkshire	115	290	—
13.	Dixon, 1930 (875). Ayrshire	119	303	—
Daphnite, &c.:				
14.	Harvey (p. 443). Tolgus mine	104	321	79
15.	Agar and Emensdorfer, 1937	112	340	48
16.	Simpson, 1937. Kalgoorlie	101	338	83
17.	,, ,, Mt. Satirist	146	311	86
18.	Simpson, 1936. Randalls	107	331	79
19.	,, ,, Holleton	97	339	17
20.	,, ,, Ninghanboun	75	275	8
21.	Pulfrey, 1933, IV. Wales	123	354	90
22.	,, ,, VII. ,, ...	121	338	91
23.	Holzner, 1937. Weilburg	118	287	59
24.	,, ,, Georg-Joseph mine ...	150	276	68
25.	,, ,, Fortuna mine	131	316	84
26.	Jung, 1930. Schmiedefeld	132	367	84
27.	Chernykh, 1926. Schmiedefeld	115	319	100
28.	,, ,, ,, ...	126	311	84
29.	Shannon, 1926. Shoshone Co.	111	424*	718
30.	Sahlbom, 1939. Mourne Mts.	103	255	95

* All iron as FeO. This analysis would lie to the right of fig. 1, beyond Orcel 7 and 35. A few new analyses cited by Winchell lie in the crowded area and have not been plotted.

following Kenngott (1866),[1] showed that his orthochlorite division could be represented by mixtures of serpentine Sp and amesite At; the solid constituents of these mixtures are indicated in fig. 1 by a straight line, which may be termed the orthochlorite line. The numerous analyses now available confirm the original observation that the orthochlorite line is not uniformly occupied by analyses: amesite is almost isolated, the main chlorite group extending from corundophilite to pennine;

[1] Kenngott (1866, pp. 247–250) showed that, after calculation in some cases of all the iron as ferrous oxide, the chlorites could be represented as isomorphous mixtures in which $MgO.SiO_2$ was replaced by Al_2O_3 'just as in haematite $FeO.TiO_2$ is assumed to proxy [for Fe_2O_3] ... According to this hypothesis we may put $AlO.AlO_2$ in place of MgO and SiO_2.' After tabulating 13 chlorites to show that $SiO_2+AlO_2 : RO+AlO : H_{[2]}O = 2 : 3 : 2$, Kenngott deduces the formula $Mg(OH)_2+2MgO.SiO_2$ for the end-member, serpentine. For 35 chlorite analyses he found that in 26 (RO+AlO) lay between the limits 3·17 and 2·86. (Holzner, 1938, p. 411, gives 16 iron-chlorites with limits for Y 6·072 and 5·919.) Kenngott thus completely anticipated present-day ideas of proxy substitution.

then there is possibly another space between pennine and aluminous antigorites. The grouping is not confined to the orthochlorite line. Only scattered analyses are found to the right of the line in fig. 1, but there is a fairly crowded area on the left of the line, clearly indicating the existence of chloritic minerals with less RO than the orthochlorites. These were placed by Tschermak in his leptochlorite division, molecules (not now accepted) such as At′, $SiAl_2MgO_8H_4$, and At″, $SiAl_2O_7H_4$, being brought in to explain the composition. Winchell included the leptochlorites in the orthochlorite series, for by regarding the Fe_2O_3 as the result of secondary oxidation of FeO he was able to increase the value assigned to the RO group. The effect of transforming R_2O_3 to 2RO is to move the representative points in fig. 1 diagonally nearer to the orthochlorite line, but the Fe_2O_3 is sometimes too low or too high for exact coincidence. It is likely, however, that at least part of the Fe_2O_3 is really a normal constituent of the R_2O_3 group, replacing alumina. Holzner (1938) has given a very detailed discussion of the iron-bearing true chlorites. Following Winchell (and Kenngott, 1866) he shows that in many cases the analyses are reduced to orthochlorite composition when all the Fe_2O_3 is represented as FeO. This he assigns to the replacement (Kunitz, 1924) $Fe''_2(OH)_4 = Fe'''_2O_2(OH)_2 + 2H$. A diminution in water content is involved, and this is not verified in the tabulated analyses. In certain other chlorites the ferric iron cannot be so explained, but must be assigned to the normal replacement of Al by Fe‴.

It is easy to select from fig. 1 those chlorites that show outstanding departure from the orthochlorite line. There are several on the right (Orcel 166, 167, 69, 35, 7) which have not so far been discussed and which would seem to merit detailed examination. Many of those on the left can be explained by the above substitution, but it will be found that several, e.g. Orcel 188, 248, 219, 9, 15, and recent 30, 20, have insufficient ferric iron. It is unlikely, however, that the substitution is solely due to oxidation of the iron. A primary substitution might well take place with $Mg''_2(OH)_4 = Al'''_2O_2(OH)_2$.

Nomenclature.—In figs. 1 and 2 the names leptochlorite, chamosite, daphnite, thuringite, and bavalite have been marked at those (approximate) compositions which were generally associated with the minerals when they were first described (cf. Dana's System, 6th edition). Perhaps the simplest usage would be to retain Tschermak's *leptochlorite* for all the analyses to the left of the orthochlorite line. *Chamosite* is the structurally different chlorite of the sedimentary rocks. *Daphnite* usually implies the more ferrous leptochlorites, while *thuringite* has

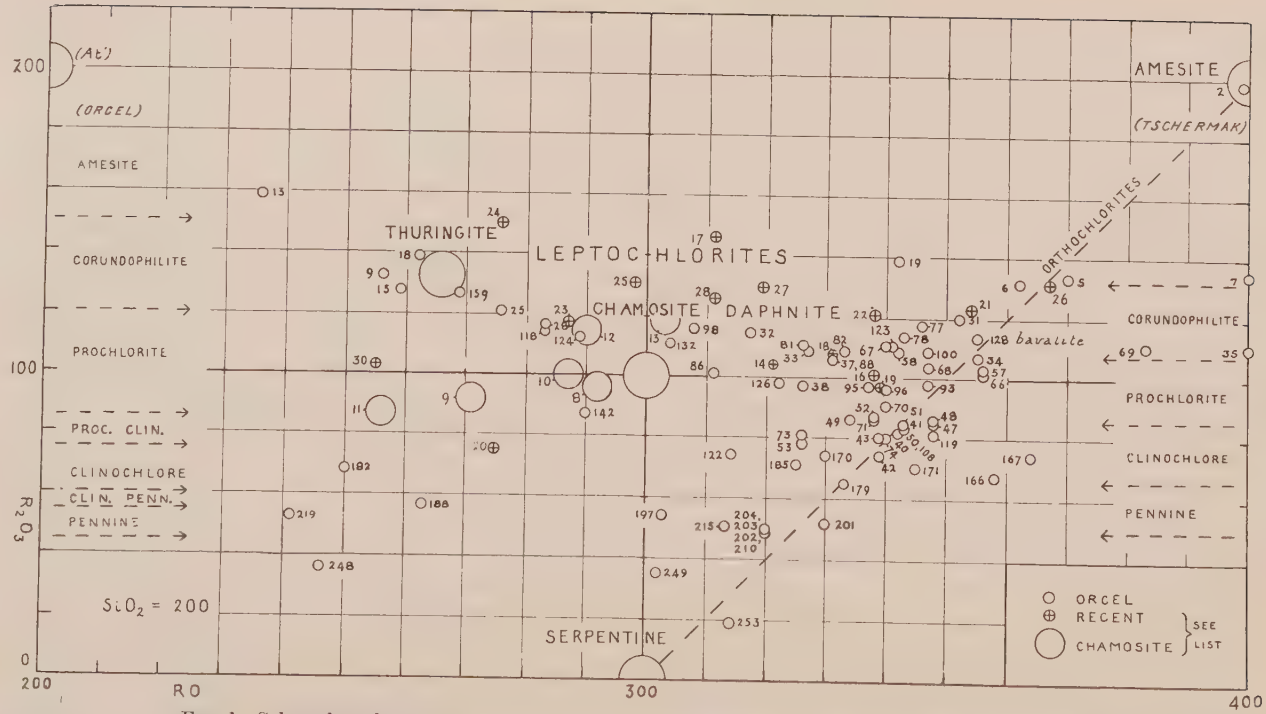


FIG. 1. Selected analyses of chlorites plotted with co-ordinates RO and R_2O_3 when $SiO_2 = 200$.
The numbers refer to Orcel (1927) and table IV (p. 452).

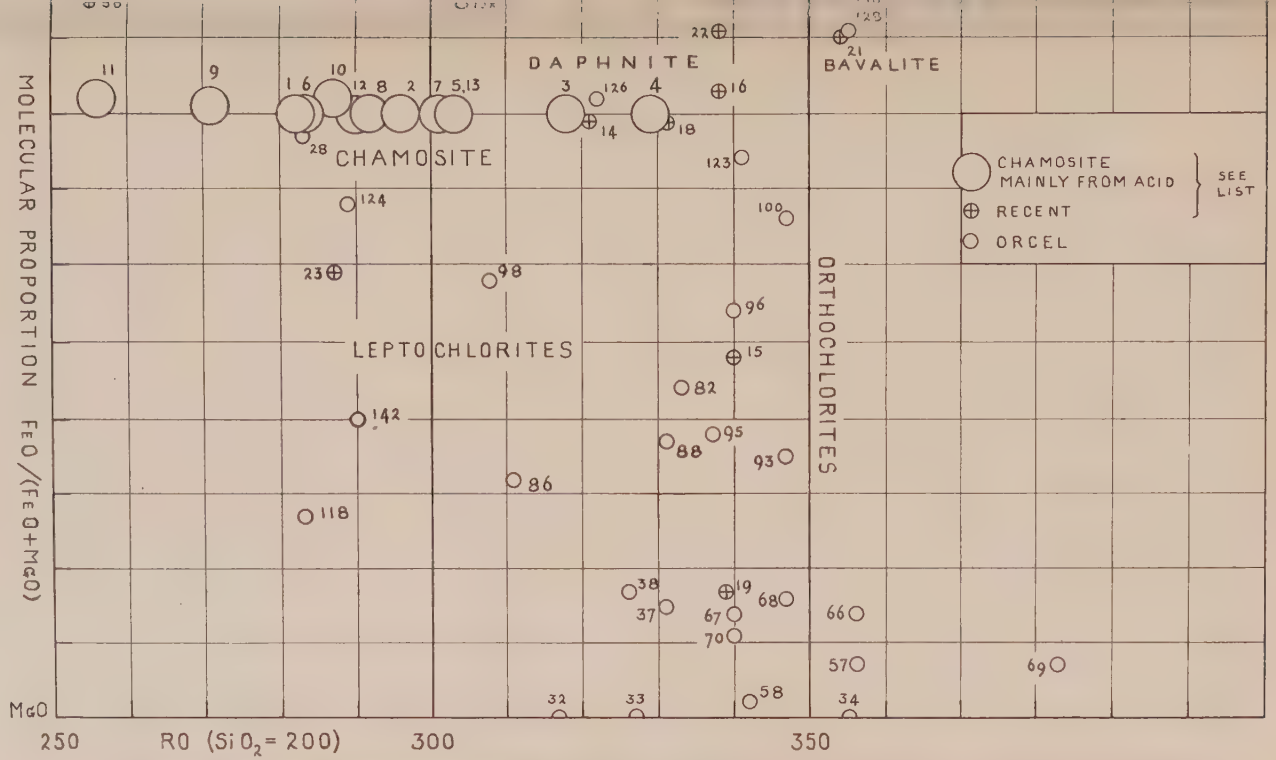


FIG. 2. Selected analyses of chamosite and other chlorites having $Al_2O_3 : SiO_2$ approximately 1 : 2, plotted with the ratios FeO : (FeO+MgO) and 200 RO : SiO_2 as co-ordinates.

been used for leptochlorites with a noteworthy amount of ferric iron. *Bavalite* is a ferrous orthochlorite at the end of the daphnite series.

Tschermak's arbitrary sub-divisions of the magnesian orthochlorite series are indicated by the names down the right-hand side of fig. 1. On the left are the sub-divisions proposed by Orcel; these apply equally to the leptochlorites, so that they divide the whole diagram into narrow horizontal strips. Additional names are used by Orcel in his tables.

Cross-section through the chlorite group.—In order to show more clearly the chemical relation of chamosite to the daphnites, &c., a cross-section has been drawn through the chlorite group along the horizontal strip $R_2O_3 = 90$–120 (this is rather narrower than the horizontal section named prochlorite by Orcel). This section includes numerous analyses with RO contents varying through chamosite to the orthochlorite line. They have been represented upon a diagram (fig. 2) having the RO content as abscissae and the molecular ratio FeO/(FeO+MgO) as ordinates. In acid extraction analyses of chamosite with carbonate present the ratio FeO/MgO is not directly determined, but it is certainly high and the value 5:1 has been assumed; the chamosites, which have been plotted as large circles, all lie near the top of the diagram.

The following relations will be evident from fig. 2. (1) As regards RO contents, the chamosites cluster near the simple ratio RO = 300; some of the extraction analyses are not very accurate but they all lie well apart from the orthochlorite line, which is intersected by the diagram at RO = 350. (2) Chlorites that have been called daphnite, together with many others that have received different names, have an RO content intermediate between chamosite and the orthochlorite line, and they occur with increasing frequency toward the latter. (3) It is generally understood that the leptochlorites are dominantly iron-bearing, but this is by no means invariably the case, for the diagram shows both ferrous chlorites (bavalite) near the orthochlorite line and magnesian chlorites near the chamosite composition. Until these minerals have been examined by X-ray methods it is not possible to say whether they are all members of the main chlorite series, but the mode of occurrence makes this very likely. (4) The orthochlorite composition forms a very well-defined limit on one side of the group: relatively few analyses contain more than 350 RO, but the existence of a few chlorites with excess RO (e.g. Orcel, 69, 35, fig. 1) seems to be established.

From this brief review of the chlorites it might on the whole be concluded that the chamosite of the iron-ores is somewhat different from the daphnites (vein-chlorites), though their composition is in one or two

ases nearly identical; only the daphnites show a gradation toward the rthochlorites. A very interesting determination of this question has een reached by Mr. Bannister as the result of the X-ray investigation.

VII. Alteration of Chamosite.

The bedded iron-ores of North Wales contain abundant chlorite: lthough the mode of occurrence corresponds with that of chamosite, he chlorite has been recrystallized, the smooth 'onion-structure' of he ooliths being replaced by roughly tangential minute flakes (Halli-ond, 1925, p. 73). Ennos and Sutcliffe found that the chlorite in these res dissolved less readily and the extracted material differed from the mple chamosite formula. These results were confirmed by Pulfrey 1933).

A similar recrystallization affects the bavalite (no. 128) analysed by rcel (1927, p. 246) (see p. 445). This was a new specimen obtained from he foot-wall of the ironstone bed (Devonian) at Bas Vallon; it was mposed of pure chlorite, as felted minute scales. Another specimen ontained garnet and stilpnomelane. Bas Vallon lies between two anite masses, and the iron-ore, which is oolitic, has apparently suffered n alteration similar to that affecting the Welsh ores.

Two of Pulfrey's specimens were pure chlorite, nearly as free from sidue as the bavalite: their molecular ratios are shown below:

	Bavalite Orcel, 128.	Llandegai Pulfrey, IV.	Pen-yr-allt Pulfrey, VII.
SiO_2 ...	200	200	200
Al_2O_3 ...	114	117	98
Fe_2O_3 ...	—	6	23
(Fe,Mg,Mn)O	355	354	351
H_2O ...	304	339	338
Sp. gr. ...	3·20	3·03	—

These are plotted in fig. 1, nos. Orcel 128, recent 21, 22.

The Llandegai mineral was a felted mass of minute hexagonal scales, ormed in a slip-plane in the ironstone bed; that from Pen-yr-allt was a reen rock, chiefly composed of felted flakes of chlorite with scattered rains of magnetite associated with stilpnomelane. The three analyses ontain more RO than chamosite and are close to orthochlorite in com-osition: it will be shown in the section dealing with X-ray investigation hat the Llandegai chlorite and Orcel's bavalite have normal chlorite tructure, and are not chamosite. On reference to fig. 1 it will be seen hat bavalite (Orcel, 128) is closely similar in ratios to the magnesian

sheridanites (Orcel, 34 and 31). Evidently the first effect of alteratio upon the chamositic ore has been to destroy the special chamosit structure and to produce bavalite, a rather more basic true chlorit which is at the orthochlorite end of the daphnite range. Anothe example of the same kind would seem to be the alteration of th Schmiedefeld chamosite (Jung, 1931) to 'thuringite' (Jung, 1930) This thuringite differs from the other thuringites, for it is an ortho chlorite in composition, not far from bavalite (cf. analysis cited i table II and point 'recent 26' near the orthochlorite line in fig. 1).

The alteration to bavalite involves an increase in RO: it seem possible that this may have been provided by the elimination of CO from chalybite, for several of the altered Welsh ores are notably fre from carbonate, though otherwise resembling ordinary ironstones.

Note.

Chlorite analyses, when calculated to atomic proportions, show re markably frequent and close agreement with the accepted X-ray formul for chlorite. This is very well exemplified in the series of iron-chlorit analyses tabulated by Holzner (1938, p. 411). The agreement somewha exceeds the expectation that might at first be formed in view of th nature of the material and the errors of analysis. It becomes of interest therefore, to inquire what deviation from complete agreement with th ideal X-ray formula will result (*a*) from the presence of, say 5 %. c quartz, clay, or mica, and (*b*) from common errors in analysis.

(*a*) Water is verified separately by Holzner, the 'solid' part of th analysis being recalculated to O = 14. Since Al is arbitrarily include with Si to make up $Al^{[4]} = 4$, the only total that is independentl verified here is $Si + Al^{[4]} + Al^{[6]} = 10$ atoms.

Calculations as in Holzner's Table VIII (1938).

	$Al^{[4]}$.	Si.	H_2O.	ΣY.	O(solid
Ideal chlorite	1·50	2·50	4·00	6·00	14·00
,, +5 % SiO_2	1·42	2·58	3·80	5·85	14·00
,, +5 % $Al_2O_3.2SiO_2.2H_2O$ ...	1·42	2·58	4·00	5·90	14·00
,, +5 % $K_2O.3Al_2O_3.6SiO_2.2H_2O$	1·25	2·75	3·86	5·91	14·00

Even in these extreme cases the agreement with $\Sigma Y = 6{\cdot}00$ is sur prisingly close. It seems clear that quite a substantial amount of man foreign minerals might be present without seriously affecting th verification.

(*b*) As regards errors in analysis, the failure to separate silica fro alumina has little influence on the atomic ratios, for by weigh

$O_2 : Al_2O_3 = 120 : 102$ so that the number of silicon atoms lost is ut equal to the additional aluminium returned. Again, the return ome ferrous iron as ferric would appear as an oxidation according to itz's or Winchell's theory. It is, of course, of the greatest interest , good chlorite analyses closely agree with the X-ray formula, but above considerations have been mentioned in order to guard against assumption that such an agreement necessarily indicates that the lysis is satisfactory and suitable for calculation.

or the orthochlorites the cell-formula $(Si,Al)_4(Mg,Al)_6O_{14}(OH)_8$, ch agrees with that deduced by Kenngott (1866) and confirmed by hermak (1891), has been verified by direct X-ray determination in mber of cases. It would seem, however, that serious difficulties exist for those chlorites (leptochlorites) which do not lie on the ochlorite line (fig. 1). Holzner's list (table VIII, 1938) certainly ts to the presence of a constant amount of $4H_2O$ in the unit cell, even n, as in Orcel no. 13, there is a very large amount of 'oxidized' e iron. Again, both the crystallization of the chlorite and its internal lation must take place below the dehydration temperature; Jung wed that all the water is evolved at about 420° C. Here, if anywhere, internal oxidation should take place, and Jung accordingly tested grey residue, after loss of 12·47 % water, by ignition in air. A gain ·54 % took place, indicating that the iron had been still in the ferrous te. Apparently, therefore, there is no internal oxidation during the plete dehydration of a chlorite in the laboratory.

Until a satisfactory explanation of the water content is obtained it uld seem that caution is necessary in applying the accepted cell- mula to the leptochlorites.

An X-ray Comparison of Chamosite, Daphnite, and other Chlorites.

(By F. A. Bannister.)

An examination made by Dr. Hallimond of many thin sections of mosite showed that the isolation of single crystals for X-ray study uld be impossible. Like many of the clay minerals, chamosite is remely fine-grained and hence amenable only to the X-ray powder thod. The thin sections showed, however, that the chamosite is of iform texture, and since only a small speck is necessary for X-ray rk it seemed probable that powder photographs of chamosite free from ier minerals could readily be obtained. Six specimens of chamosite

(pl. XIX, figs. 1–6) were selected for this work including that from Frodi
ham, Lincolnshire (fig. 1), and other material previously studied by Ha
mond and other workers. A specimen of chamosite from the type loca
has also been photographed (fig. 3). Figs. 7–14 include daphnite fig.
(chemical analysis table I), H. Jung's 'thuringite' (= bavalite) fig
cronstedtite fig. 7, and some other iron-rich chlorites for comparison

The powder photographs reproduced in pl. XIX and the measu
spacings of the powder lines given in table V show that all six pho
graphs of chamosite (figs. 1–6) are very similar to each other, but
distinct from those of thuringite, daphnite, &c. Fig. 5 shows a flecl
line of medium intensity, 3·29 Å., due to quartz; and a weak line 2·75
in figs. 4 and 6 may be due to admixed chalybite. The remain
photographs show no lines due to admixture with quartz, chalyb
iron oxide, clay, or mica minerals. A specimen of the Lias clay fo
inches above the Frodingham ironstone from the Yarborough
Frodingham, Lincolnshire (not reproduced in the plate), shows lines
to quartz, chamosite, and a member of the montmorillonite-nontron
family. Probably 5 % or more of quartz and chalybite and 10 %
more of a clay or mica mineral could readily be detected on the chamos
photographs. A specimen of oolitic material collected by Dr. L.
Spencer from the Northampton ironstone at Burford Lodge
Kettering district, Northamptonshire, showed, in addition to coars
flecked lines of chalybite, continuous lines of chamosite resembling m
closely figs. 1 and 4. There is no difficulty, therefore, in recognizing
pattern of chamosite in a powder photograph of a mixture of two
three minerals.

When allowance has been made for the lines due to admixed miner
there are still apparent differences between the chamosite photograp
they are all very similar, but not identical. There may be three possi
causes for this:

(1) Different degrees of orientation in different specimens.

(2) Variation in crystal size from one specimen to another.

(3) Variation in chemical composition, cell size, and crystal structu

The last possibility is not excluded, since complete chemical analy
are not available. Of the other two possibilities the first is most lik
to affect the intensities of the basal diffractions relatively to those
other diffracting planes. The variations in intensity, however, are m
marked in lines which have not been indexed, but which are certai
not given by diffraction from (001). Variation in crystal size and
fection of crystallization may readily account for the observed dif

es, but, in the absence of complete chemical analyses and of single-
stal measurements, the differences between the chamosite photo-
phs remain unexplained. Nevertheless, the chamosite photographs
m a distinctive group showing marked differences from the patterns
daphnite, thuringite, bavalite, corundophilite, and aphrosiderite, all
which give patterns of normal chlorite type. As a matter of interest,
er well-known chlorites such as amesite and cronstedtite, figs. 14
7, give patterns distinct from each other and also from the normal
rites. Evidently the chlorite family includes a number of minerals
ch yield distinctive patterns. Curiously enough the chamosite from
type locality differs from the other chamosite photographs and shows
rtain affinity to patterns of the cronstedtite here studied.

t should be mentioned that the data in table V agree well with those
ed by McMurchy for iron-bearing chlorites. He found that amesite
s a pattern different from that of the normal chlorite, and my
surements for amesite are also in close agreement with his. We have
nded the work of H. Jung, who also found differences between the
ay patterns of chamosite and thuringite, but he did not show that
latter mineral gives the normal chlorite pattern. Also, we now have
ay evidence showing that bavalite and thuringite have the same
tal structure. The chlorite of the Welsh iron-ore, fig. 12, is of
ial interest, for though occurring in a typical chamositic ironstone
s normal chlorite structure. It is chemically similar to bavalite.
are indebted to Dr. G. Nagelschmidt for the loan of an X-ray photo-
ph of Orcel's bavalite which is also identical with the normal chlorite
tern.

No attempt has been made to deduce the cell dimensions or cell
tents of chamosite, since it is questionable whether powder photo-
phs alone can be indexed reliably when they show distinct differences
m the normal chlorite type. For daphnite, which, as we have shown,
ongs to the normal chlorite type, we have, however, carried out
gle-crystal X-ray measurements, and these are given, together with
contents calculated directly from the chemical analysis and specific
vity, in table VI. Single-crystal measurements for cronstedtite from
neal Jane agree well with those given by Gossner (1935) for that
neral from Kisbánya. Recalculation of available chemical analyses
nich show much variation) indicates that, if the crystal structure of
nstedtite is closely similar to that suggested by Pauling and
Murchy for the normal chlorites, then considerable replacement of
ca by ferric iron atoms in the hexagonal silicon-oxygen sheets must

TABLE V. Spacings in Ångström units of lines of X-ray powder photographs (pl. XIX, figs. 1–14) of chamosite, daphnite, and other chlorites. Estimated intensities: *w* weak, *m* medium, *s* strong, *vw* very weak, &c.

Fig. 1.	Fig. 2.	Fig. 3.	Fig. 4.	Fig. 5.	Fig. 6.	Fig. 7.	Fig. 8.	Fig. 9.	Fig. 10.	Fig. 11.	Fig. 12.	Fig. 13.	Fig. 14.
6·98 *vvs*	6·72 *vs*	6·98 *s*	6·85 *vs*	6·72 *s*	6·76 *vs*	6·72 *vs*	7·03 *vs*	6·76 *s*	6·80 *s*	6·72 *s*	6·94 *vs*	6·76 *s*	6·76 *vs*
4·53 *m*	4·53 *vvw*	4·53 *w*	4·53 *vw*	4·49 *w*	4·53 *w*	4·62 *vw*	4·68 *s*	4·62 *m*	4·62 *w*	4·53 *ms*	4·64 *m*	4·62 *w*	4·53 *m*
—	—	—	—	—	—	—	—	—	—	—	—	—	3·76 *w*
3·51 *s*	3·42 *s*	3·51 *s*	3·48 *m*	3·47 *s*	3·42 *s*	3·49 *s*	3·51 *vs*	3·47 *s*	3·48 *s*	3·42 *s*	3·50 *s*	3·47 *m*	3·41 *s*
—	—	—	—	[3·29 *m*]	—	—	—	—	—	—	—	[3·28 *vw*]	—
—	—	—	2·74 *mw*	—	2·75 *w*	2·70 *ms*	2·80 *mw*	2·78 *vvw*	2·78 *w*	2·75 *vvw*	2·80 *w*	2·79 *vw*	—
2·66 *w*	2·62 *w*	2·65 *mw*	2·63 *w*	—	2·63 *w*	—	—	—	2·65 *vvw*	—	—	—	—
—	—	—	—	—	—	—	2·59 *m*	2·59 *m*	2·59 *m*	—	2·57 *ms*	—	2·58 *m*
—	—	—	—	—	—	—	2·54 *m*	2·54 *mw*	2·54 *m*	2·54 *m*	—	2·55 *mw*	—
2·48 *m*	2·46 *s*	—	2·49 *s*	2·46 *vs*	2·47 *ms*	—	2·44 *mw*	2·44 *mw*	2·45 *mw*	—	2·46 *m*	—	2·46 *ms*
—	—	2·39 *m*	—	—	—	2·41 *ms*	2·42 *mw*	2·42 *mw*	2·42 *mw*	—	2·41 *m*	2·38 *mw*	—
—	2·35 *ms*	—	—	—	—	2·33 *vw*	—	—	—	2·36 *w*	—	—	—
—	—	—	—	—	—	2·27 *vw*	2·25 *w*	2·25 *mw*	2·25 *mw*	2·25 *w*	2·27 *m*	2·25 *w*	2·29 *w*
2·12 *w*	2·10 *ms*	—	2·12 *ms*	2·14 *m*	2·10 *vw*	—	—	—	—	—	—	—	2·09 *w*
—	1·98 *w*	2·00 *vw*	—	—	—	2·02 *m*	2·00 *m*	2·00 *m*	2·00 *m*	1·98 *m*	2·02 *s*	2·00 *m*	1·98 *w*
—	—	—	—	—	—	1·96 *vw*	—	—	—	—	—	—	—
—	1·86 *vvw*	—	—	—	—	—	1·88 *vw*	1·88 *w*	1·88 *w*	1·86 *w*	1·90 *m*	1·88 *vvw*	1·90 *m*
—	—	—	—	—	—	—	1·81 *vw*	1·81 *vw*	1·81 *vvw*	1·81 *vw*	1·83 *w*	—	—
1·74 *w*	1·75 *m*	—	1·76 *m*	1·74 *m*	1·73 *w*	—	—	1·71 *vvw*	1·76 *vvw*	—	—	—	1·73 *vw*
—	1·64 *vw*	—	—	—	—	1·67 *mw*	—	1·63 *w*	1·66 *vvw*	1·64 *vw*	1·67 *vw*	—	1·68 *vw*
1·55 *ms*	1·54 *s*	1·55 *m*	1·55 *m*	1·54 *ms*	1·54 *ms*	1·58 *s*	1·56 *mw*	1·55 *s*	1·55 *ms*	1·57 *m*	1·56 *s*	1·55 *ms*	1·58 *vw*
—	—	—	—	—	—	1·55 *mw*	1·54 *m*	—	—	1·54 *m*	1·53 *mw*	—	1·52 *ms*
1·52 *m*	1·51 *m*	1·52 *w*	1·52 *w*	1·50 *w*	1·50 *w*	—	1·50 *w*	1·51 *mw*	1·51 *w*	1·50 *vw*	—	1·51 *w*	1·50 *w*
—	1·46 *m*	—	1·47 *w*	1·46 *vw*	—	1·44 *mw*	—	—	—	—	1·43 *vw*	—	1·45 *w*
1·42 *mw*	1·41 *w*	1·42 *w*	1·42 *w*	1·41 *vw*	1·42 *vw*	—	1·41 *vvw*	1·42 *w*	1·42 *vvw*	1·41 *vw*	—	1·41 *vvw*	—
—	—	—	—	—	—	1·37 *vw*	1·39 *w*	1·39 *mw*	1·39 *w*	1·38 *ms*	1·39 *m*	1·39 *vw*	1·39 *mw*
—	—	—	—	—	—	—	—	1·34 *w*	1·33 *w*	—	1·34 *w*	—	1·35 *vw*
1·32 *w*	1·32 *w*	—	—	—	1·32 *w*	1·32 *w*	1·32 *vw*	1·31 *w*	1·30 *vw*	1·32 *w*	1·31 *vw*	—	1·30 *vw*

ake place. Such a replacement needs checking by a proper crystal tructure study of cronstedtite, and until that is available I hesitate to ublish any cell formula for that mineral.

ABLE VI. Cell dimensions and contents of daphnite, Tolgus mine, Cornwall. (See table I.)

a.	*b*.	*c'*.	Sp. gr.	*n*.
5·40	9·36	28·2 Å.	3·08	71·3

Si.	Al.	Fe'''.	Fe''.	Mn.	Mg.	Ca.	H.
10·82	10·58	0·71	13·48	0·18	3·70	0·05	31·22

c' denotes the *c* spacing and not the cell dimension *c*.
n denotes calculated oxygen content.

The remaining atoms are then deduced assuming 72 oxygen atoms per unit cell. he cell contents if grouped in accordance with the usual structure formula are:

Si.	Al.	Al.	Fe'''.	Fe''.	Fe''.	Mg.	Ca.	Mn.	H_2O.
10·82	5·18	5·40	0·71	5·89	7·59	3·70	0·05	0·18	15·61
16		12			11·52				

Summary.

New analyses are given of daphnite from Tolgus mine, Cornwall, and hamosite from Frodingham, Lincolnshire. Earlier analyses are dis-ssed and a graphical representation is given of selected chlorite nalyses. X-ray examination shows that daphnite has normal chlorite tructure like that of clinochlore, but chamosite has a special structure f chlorite type. X-ray data for other chlorites are discussed. Under ncipient metamorphism chamosite alters to bavalite, which has normal hlorite structure.

References.

GAR (W. M.) and EMENDORFER (E. H.), 1937. Manganiferous prochlorite from Hawleyville, Conn. Amer. Journ. Sci., ser. 5, vol. 34, pp. 77–80. [M.A. 7–258.]

HERNYKH (V. V.) in KURNAKOV (N. S.) and CHERNYKH (V. V.), 1926. Physico-chemische Untersuchung der Serpentine und Chlorite. Mém. Soc. Russe Min., ser. 2, vol. 55, pp. 183–194.

EANS (T.), 1934 a. The spherulitic ironstones of west Yorkshire. Geol. Mag. London, vol. 71, pp. 49–65.

— 1934 b. Some oolitic ironstones from the Coal Measures of Yorkshire. Trans. Leeds Geol. Assoc., vol. 5, pp. 161–187.

IXON (B. E.), 1930. Summary of Progress for 1929, Mem. Geol. Surv. Great Britain, pt. I, p. 98.

YLES (V. A.), 1930. Economic geology of the Ayrshire coalfields. Area III. Mem. Geol. Surv. Scotland, pp. 67–68.

OSSNER (B.), 1935. Über Cronstedtit von Kisbánya. Zentr. Min., Abt. A, pp. 195–201. [M.A. 6–333.]

ALLIMOND (A. F.), 1925. Iron ores: bedded ores of England and Wales. Spec. Rep. Min. Res., Mem. Geol. Surv. Great Britain, vol. 29. With appendix by

F. R. Ennos and R. Sutcliffe: On the estimation of the chlorite in sedimentary rocks.

Hallimond (A. F.), 1926. On the chemical classification of the mica group. II The basic micas. Min. Mag., vol. 21, pp. 25–33.

Holzner (J.), 1938. Eisenchlorite aus dem Lahngebiet. . . . Neues Jahrb. Min. Abt. A, Beil.-Bd. 73, pp. 389–418. [M.A. **7**–408.]

Jung (H.) and Köhler (E.), 1930. Untersuchungen über den Thuringit von Schmiedefeld in Thüringen. Chem. Erde, vol. 5, pp. 182–200. [M.A. **4**–334.]

Jung (H.), 1931. Untersuchungen über den Chamosit von Schmiedefeld i. Thür. Chem. Erde, vol. 6, pp. 275–306. [M.A. **5**–40.]

Kenngott (A.), 1866. Mitt. über Pyrophyllit . . . Vierteljahrsschrift der Naturforsch. Gesell. Zürich, vol. 11, pp. 240–259.

Kunitz (W.), 1924. Die Beziehungen . . . der Glimmergruppe. Neues Jahrb. Min. Abt. A, Beil.-Bd. 50, pp. 365–413. [M.A. **2**–424.]

McMurchy (R. C.), 1934. The crystal structure of the chlorite minerals. Zeits. Krist., vol. 88, pp. 420–432. [M.A. **6**–45.]

Orcel (J.), 1927. Recherches sur la composition chimique des chlorites. Bull. Soc. Franç. Min., vol. 50, pp. 75–454.

Pulfrey (W.), 1933. The iron-ore oolites and pisolites of North Wales. Quart. Journ. Geol. Soc. London, vol. 89, pp. 401–430.

Radley (E. G.), 1920. The Mesozoic rocks of Applecross. . . . Mem. Geol. Surv. Scotland, p. 35.

Sahlbom (N.) in Nockolds (S. R.) and Richey (J. E.), 1939. Replacement veins in the Mourne Mts. granites, N. Ireland. Amer. Journ. Sci., vol. 237, pp. 27–47. [M.A. **7**–305.]

Shannon (E. V.), 1926. The minerals of Idaho. Bull. U.S. Nat. Mus., no. 131, p. 378. [M.A. **3**–130.]

Simpson (E. S.), 1936. Contributions to the mineralogy of Western Australia. Series IX. Journ. Roy. Soc. W. Australia, vol. 22, pp. 1–18. [M.A. **6**–363.]

—— 1937. Ditto. Series X. Ibid., vol. 23, pp. 17–35. [M.A. **7**–114.]

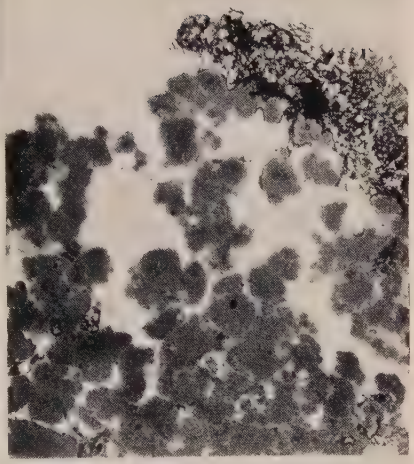
Tschermak (G.), 1891. Die Chloritgruppe, II. Theil. Sitzungsber. Akad. Wiss. Wien, Math.-nat. Kl., vol. 100, Abt. 1, pp. 29–107.

Wilson (G. V.), 1922. The Ayrshire bauxitic clay. Mem. Geol. Surv. Scotland. [M.A. **2**–556.]

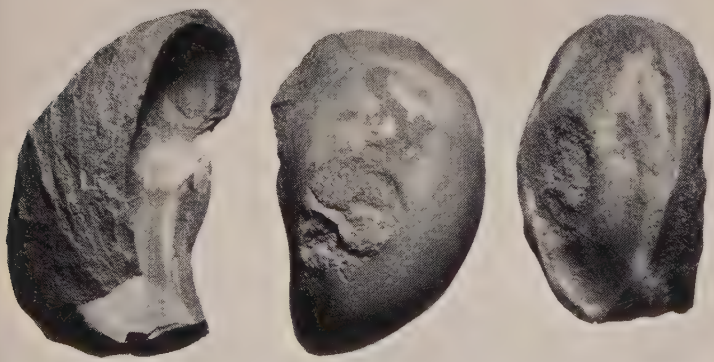
—— 1930. Geology of North Ayrshire. Mem. Geol. Surv. Scotland, pp. 209–214.

Winchell (A. N.), 1936. A third study of chlorite. Amer. Min., vol. 21, pp. 642–651. [M.A. **6**–532.]

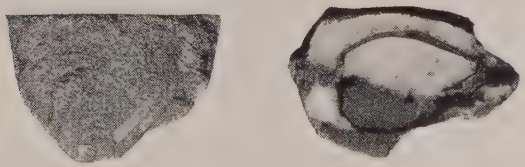
1 x 28



2 x 28

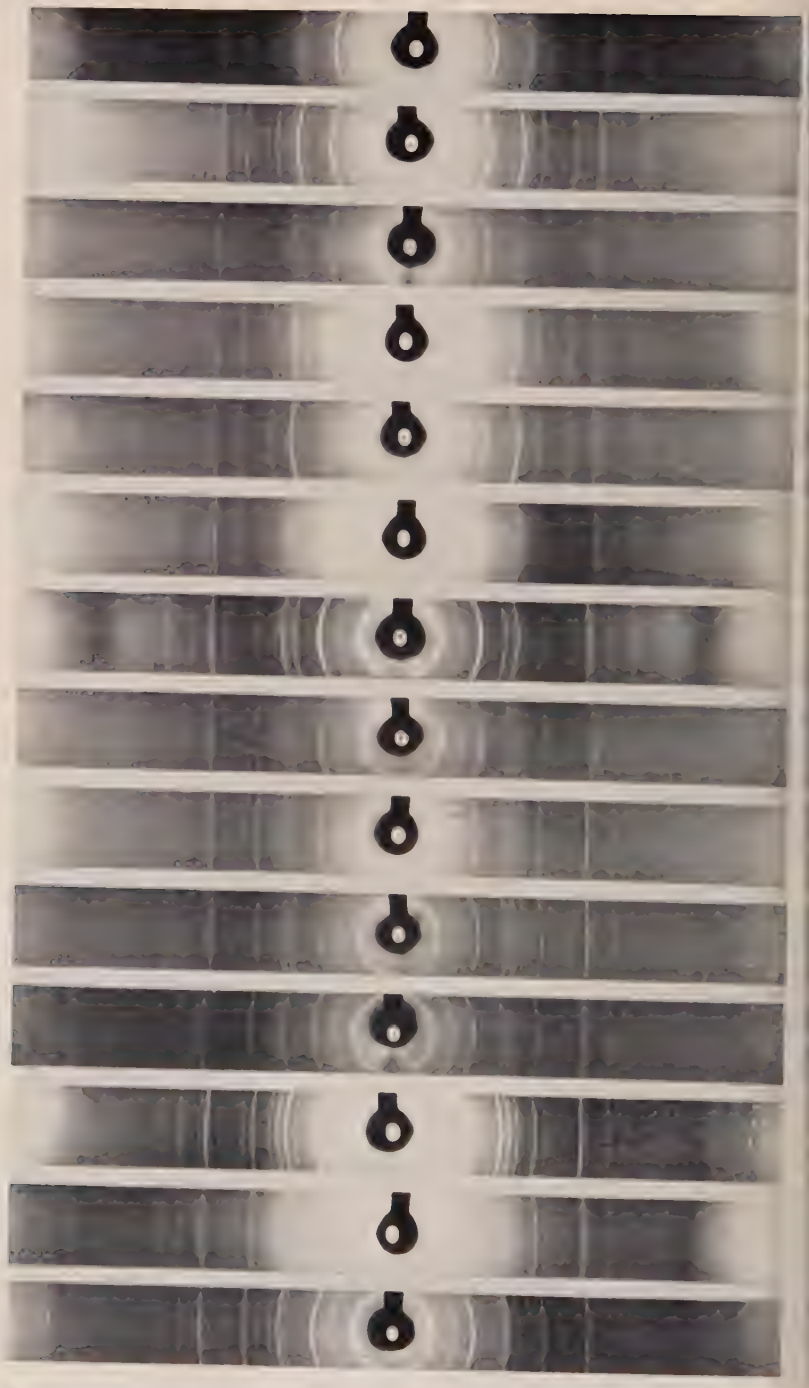


3 x 1



4 x 1

A. F. Hallimond: Daphnite and Chamosite.



F. A. Bannister - X-ray photographs of Chamosite, Daphnite, etc.

Explanation of Plates XVIII and XIX.

Plate XVIII. Fig. 1. Daphnite: fan-like aggregates filling the space between quartz crystals. From a vein at 1450 feet, Tolgus mine, Cornwall. ×28.

Fig. 2. Chamosite: granules of minutely crystalline chlorite in coarsely crystalline calcite; near the top there has been secondary replacement of the calcite by a group of elongated rhombohedra of chalybite with iron oxide. From the interior of a *Cardinia* shell (fig. 4) from the ironstone bed, Frodingham, Lincolnshire. ×28.

Fig. 3. Shell of *Gryphaea*: upper and lower valves, with a mould of the interior formed of chamosite-chalybite mud. From the ironstone bed, Frodingham, Lincolnshire. Natural size.

Fig. 4. Shell of *Cardinia*: cut in two, showing (left) the exterior with adherent oolitic ironstone; (right) polished section of the interior, filled partly with coarsely crystalline calcite, partly with granular chamosite (cf. fig. 2), but no ooliths. From the ironstone bed, Frodingham, Lincolnshire. Natural size.

Plate XIX. A series of X-ray powder photographs of chamosites, daphnite, and other chlorites reproduced so that 10 cm. is equivalent to 15 cm. on the original film. All the photographs were taken with unfiltered cobalt-radiation of wavelength 1·787 Å. in a cylindrical camera of 6·04 cm. diameter. Small fragments were selected from material studied and were not powdered unless specifically stated below:

Fig. 1. Green filling of shell of *Cardinia* from the Frodingham ironstone, Lincolnshire. No. 8, table IV; chemical analysis, table II.

Fig. 2. Chloritic clay, Ayrshire. No. 12, table III; Geol. Survey, Lab. no. 874.

Fig. 3. Chamosite-chalybite mudstone, Chamoson, Valais, Switzerland. B.M. 35331.

Fig. 4. Pecten seam, Cleveland, Yorkshire. No. 5, table III; Geol. Survey, M.I. 14045.

Fig. 5. Chamositic ironstone, Coal Measures, Yorkshire. No. 12, table IV.

Fig. 6. Oolith from Raasay ironstone. No. 11, table IV; Geol. Survey, Lab. no. 458 A.

Fig. 7. Powdered crystals of cronstedtite, Wheal Jane, Cornwall. Geol. Survey, Ludlam collection, no. 2578.

Fig. 8. Powdered corundophilite, Chester, Massachusetts, U.S.A. Geol. Survey, Ludlam collection, no. 7944.

Fig. 9. Bavalite from the Lower Silurian, Schmiedefeld, Thuringia, Germany. Geol. Survey, M.I. 25323, presented by H. Jung, 1934.

Fig. 10. Thuringite, Saalfeld, Harz, Germany. B.M. 32701.

Fig. 11. Powdered crystals of aphrosiderite, Salida, Colorado, U.S.A. B.M. 1924,623.

Fig. 12. Chlorite rock (bavalite), Llandegai, North Wales. No. 21, table IV; Geol. Survey, M.I. 23877.

Fig. 13. Powdered daphnite, Tolgus mine, Cornwall. Chemical analysis, table I; Geol. Survey, M.I. 16006.

Fig. 14. Powdered amesite from Chester, Massachusetts, U.S.A.

Crystallography of aramayoite.

By Harry Berman and C. W. Wolfe,
Harvard University, Cambridge, Massachussetts.

[Read November 9, 1939.]

THE original description of aramayoite by Spencer in 1926[1] contained only a qualitative discussion of the crystallography, because suitable crystals for a more rigorous treatment were not found. The pseudo-tetragonal symmetry was recognized, and cleavages were noted, but only one was defined. Twinning was later observed in polished section by Schneiderhöhn and Ramdohr,[2] but undefined. Yardley[3] demonstrated the triclinic symmetry of aramayoite by the Laue method, and determined the spacings of a considerable number of planes in the crystal. From these data she formulated a unit cell and correlated the X-ray data with Spencer's crystallographic results.

Several specimens of aramayoite found in our recently acquired Ahlfeld Bolivian collection contained small but excellent crystals. Measurement of these indicated that the Yardley X-ray crystallography was not consistent with an adequate morphological treatment of the form-development. The twenty-seven forms found by us lead to an obvious crystallographic unit (fig. 1), bearing a rather complex relationship to the Yardley unit. In order to test the suitability of the latter, we repeated the X-ray examination by the modern Weissenberg method and found complete accordance with our morphological treatment, as will be shown below.

Crystal Measurements.—The axis [001] of the zone containing the perfect platy cleavage (010) and the good cleavage (100) was set vertical for the two-circle measurements in order to facilitate the graphical choice of the proper unit.

Table I is a resume of the measurements, together with observations of frequency and quality for forms, on four of the best measured crystals. Fig. 2 is a drawing of crystal number 8 with the more prominent forms figured. About half of the forms are obtained from 'A' measurements.

[1] L. J. Spencer, Min. Mag., 1926, vol. 21, p. 156.

[2] H. Schneiderhöhn and P. Ramdohr, Lehrbuch der Erzmikroskopie, 1931, vol. 2, p. 388.

[3] K. Yardley, Min. Mag., 1926, vol. 21, p. 163.

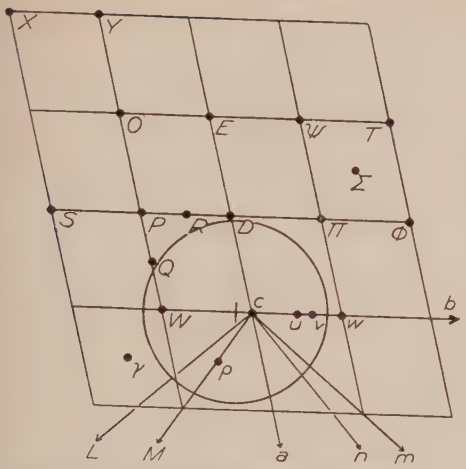


FIG. 1. Aramayoite: gnomonic projection.

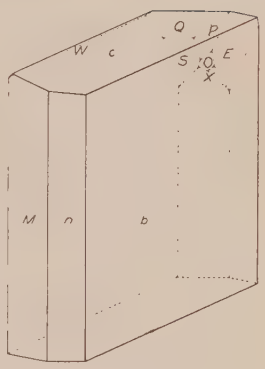


FIG. 2. Crystal of aramayoite.

All of the pinakoidal forms were present on two crystals; 0*kl*, *h*0*l*, and *hk*0 forms with simple indices were found on most crystals. The indices of no form are greater than 3, indicating a simple relation between the chosen unit and the form development.

TABLE I. Aramayoite: Crystallographic Measurements.

Forms.	Measured range.				Faces measured.	Crystal number.	Weighted average.		General quality ('A'-best).
	ϕ.		ρ.			2 6 7 8	ϕ.	ρ.	
(001)	−0° 19′	−0° 22′	11° 00′	10° 41′	3	— × × ×	0° 00′	10° 41′	B striat.
(010)	—	—	—	—	8	× × × ×	0 00	90 00	A cleav.
(100)	75 52	76 34	90 00	90 00	4	× × — ×	75 52	90 00	C line cleav.
(110)	41 25	—	—	—	1	× — — —	41 25	90 00	C line
(1$\bar{1}$0)	−55 36	56 43	—	—	5	× × × ×	−56 10	90 00	A med.
(2$\bar{3}$0)	−40 25	—	—	—	1	— × — —	−40 25	90 00	C striat.
(320)	—	—	—	—	1	— — — ×	50 13	90 00	A med.
(012)	—	—	34 32	35 02	3	× × — ×	0 00	34 43	A med.
(023)	—	—	39 39	40 43	3	× × — ×	0 00	40 16	B sm.
(011)	—	—	49 28	49 35	2	— × × —	0 00	49 32	A sm.
(0$\bar{1}$1)	—	—	—	—	1	— — — ×	180 00	38 02	A sm.
(1$\bar{0}$1)	—	—	—	—	1	× — — —	−94 35	46 42	D lge.
(2$\bar{0}$1)	−99 35	−99 42	64 57	65 17	2	× — — ×	−99 39	65 07	A lge.
(1$\bar{1}$1)	—	—	—	—	1	— — × —	−49 44	54 26	C dot
(3$\bar{3}$2)	—	—	—	—	1	— — × —	−52 04	64 06	C dot
(2$\bar{2}$1)	—	—	—	—	1	— — × —	−38 46	72 45	C dot
(1$\bar{2}$1)	−28 29	−29 39	65 04	65 27	2	— × × —	−29 04	65 16	A lge.
(2$\bar{1}$1)	—	—	—	—	1	— — × —	−72 26	67 10	D sm.
(1$\bar{1}$1)	—	—	—	—	1	— — — ×	−134 57	56 49	B sm.
(1$\bar{2}$2)	—	—	—	—	1	— — — ×	−150 16	46 50	A med.
(2$\bar{1}$2)	—	—	—	—	1	× — — —	−119 54	50 56	D line
(1$\bar{2}$1)	−152 24	−152 30	66 16	66 46	2	× — — ×	−152 30	66 46	B sm.
(2$\bar{1}$1)	—	—	—	—	1	— — — ×	−121 51	68 30	A med
(3$\bar{1}$1)	—	—	—	—	1	— — — ×	−116 36	74 29	B sm.
(3$\bar{2}$1)	—	—	—	—	1	— — — ×	−129 29	76 49	E dot
(1$\bar{1}$2)	—	—	—	—	1	— — — ×	+106 42	31 22	D sm.
(1$\bar{3}$2)	—	—	—	—	1	— — — —	+149 10	53 00	C dot

TABLE II. Aramayoite: Angle Table.

Triclinic; pinakoidal—$\bar{1}$.

$a : b : c = 0{\cdot}8753 : 1 : 0{\cdot}9406$; $\alpha = 100° 22'$, $\beta = 90° 00'$, $\gamma = 103° 54$
$p_0 : q_0 : r_0 = 1{\cdot}0889 : 0{\cdot}9690 : 1$; $\lambda = 79° 19'$, $\mu = 87° 24\frac{1}{2}'$, $\nu = 75° 52'$
$p_0' = 1{\cdot}1081$, $q_0' = 0{\cdot}9861$; $x_0' = 0° 00'$, $y_0' = 0{\cdot}1887$

Form.	ϕ.	ρ.	A.	B.	C.	Z.*
c (001)	0° 00′	10° 41′	87° 24½′	79° 19′	—	90° 00′
b (010)	0 00	90 00	75 52	—	79° 19′	—
a (100)	75 52	90 00	—	75 52	87 24½	0 00
m (110)	40 32	90 00	35 20	40 32	81 54	0 00
n (320)	49 11	90 00	26 41	49 11	83 02½	0 00
M (1$\bar{1}$0)	123 39½	90 00	47 47½	123 39½	95 54	180 00
L (2$\bar{3}$0)	138 21½	90 00	62 29½	138 21½	97 58	180 00
u (012)	0 00	34 17	82 05½	55 43	23 36	90 00
v (023)	0 00	40 14	80 55½	49 46	29 33	90 00
w (011)	0 00	49 35½	79 17	40 24½	38 54½	90 00
W (0$\bar{1}$1)	180 00	38 34	98 45½	128 34	49 15	270 00
D ($\bar{1}$01)	−94 21½	47 08½	136 04	93 11½	48 57	−42 56½
E ($\bar{2}$01)	−99 19	65 20½	154 54	98 27½	67 29½	−24 57
P ($\bar{1}\bar{1}$1)	−134 49½	56 34½	135 52	126 02½	64 23½	−42 56½
ρ (1$\bar{1}$2)	107 28	29 23½	65 17½	98 28	34 01	−118 15
Π ($\bar{1}$11)	−49 55½	54 33	118 27	58 22	48 09	137 03½
Σ ($\bar{3}$32)	−51 56½	63 58	123 25½	56 22	57 43½	148 11
T ($\bar{2}$21)	−53 00	69 37	126 01½	55 39½	63 27½	155 03
Q (1$\bar{2}$2)	−150 03½	47 06½	120 38½	129 24½	56 33	−61 45
Y (1$\bar{3}$2)	155 03½	51 52	81 31	135 30	61 40½	−118 15
R (2$\bar{1}$2)	−118 09	50 38	138 35½	111 23½	56 14½	−42 56½
S (1$\bar{2}$1)	−152 23	66 40	127 41½	144 27	76 12½	−42 56½
Φ ($\bar{1}$21)	−29 37	65 18	104 02	37 50	56 09	137 03½
O (2$\bar{1}$1)	−121 55	68 27	152 20	119 27	74 21	−24 57
Ψ ($\bar{2}$11)	−73 30	65 57½	141 47½	74 58	63 21½	155 03
Y (3$\bar{1}$1)	−116 31½	74 29½	160 14½	115 29½	79 27½	−17 14
X (3$\bar{2}$1)	−128 50	76 25	152 01	127 33½	83 14	−17 14

* Z = meridian co-ordinate with (010) polar and meridian co-ordinate of (100) = 0° 00′. 'B' or its supplement = angular distance to (010) as pole. The relationship is $Z = \cot X' = \cot \xi_0$.

The elements in table II were calculated from measurements of 'A' quality forms. In addition to the co-ordinate angles and interfacial angles to the pinakoids, the last column, 'Z', is the meridian co-ordinate from (100) as zero when (010), the platy face, is polar; the column 'B' gives the angular distance in this orientation. For purposes of comparison between measurements of different crystals these co-ordinate angles for the polar face-adjustment, following Hey,[1] have been found useful. The angle table, therefore, serves as a means of checking measurements in both settings.

[1] M. H. Hey, Min. Mag., 1934, vol. 23, p. 560.

The orientation here given differs from that of Yardley in the following way:

Yardley.	Berman & Wolfe.
$(\bar{3}\bar{3}1)$	(600)
(001)	$(0\frac{3}{2}0)$
$(\bar{3}31)$	(006)
(010)	$(\bar{1}01)$
(101)	$(\bar{1}2\bar{1})$
(100)	$(\bar{1}\frac{1}{2}\bar{1})$

The transformation formulae are:

Yardley to Berman & Wolfe	$(\bar{1}\bar{1}0)/(\frac{1}{2}0\frac{3}{2})/(\bar{1}10)$
Berman & Wolfe to Yardley	$(\frac{1}{2}0\frac{1}{2})/(\frac{1}{2}0\frac{1}{2})/(\frac{1}{6}\frac{2}{3}\frac{1}{6})$

The cleavage, observed by Spencer and made $(\bar{3}\bar{3}1)$ by Yardley, is (100) in our orientation. As will be shown in the X-ray discussion, the second-order reflection (002) of Yardley is our third-order reflection (030); the $(\bar{3}31)$ of Yardley is our (006); the $(\bar{3}\bar{3}1)$ of Yardley is our (600). These relations introduce the complexities of the transformation formulae.

Twinning.—Many cleavage plates from our specimens showed a sharp line running diagonally across the plate. Several inferior crystals with poor faces showed that this line on the cleavage surface represented the trace of the composition-plane of a twin. The measurements indicated that the twinning is about the axis $[\bar{1}01]$ with the composition plane near $(\bar{1}01)$.

A gnomonic projection with $[\bar{1}01]$ as pole shows an axis of two-fold pseudosymmetry. Under these circumstances twinning on the axis produces a near superposition of the projection of one individual on the other. In the Friedel sense the twinning has an index of 1, with a small obliquity. When no re-entrant angle shows on the crystals, twinning may well be concealed. A well-defined parting is developed parallel to the composition-plane $(\bar{1}01)$.

X-ray measurements.—A crystal plate showing the two cleavages was used for the X-ray examination with the Weissenberg goniometer. Rotation was about the [001] axis; zero-layer and first-layer pictures were studied (figs. 3 and 4). The periodicity along [001] was obtained from the rotation picture. On the zero-layer, fifty-three reflections were indexed. For $0k0$, reflections at $k = 3, 6, 9$ were observed; for $h00$, reflections for $h = 2, 6$ were observed. In general, the reflections with h odd were weak or missing. In the first-layer series $hk1$, the reflections for $h =$ odd were well shown. The projected reciprocal lattice, derived

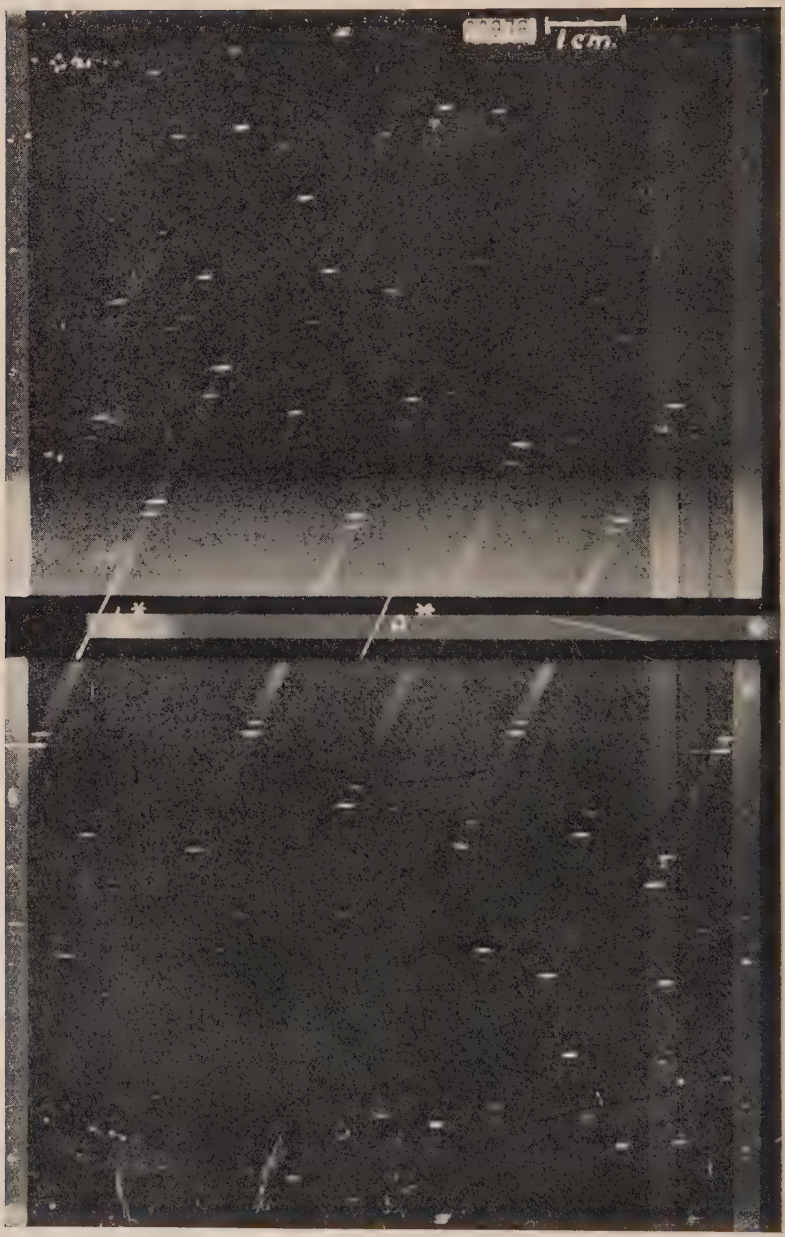
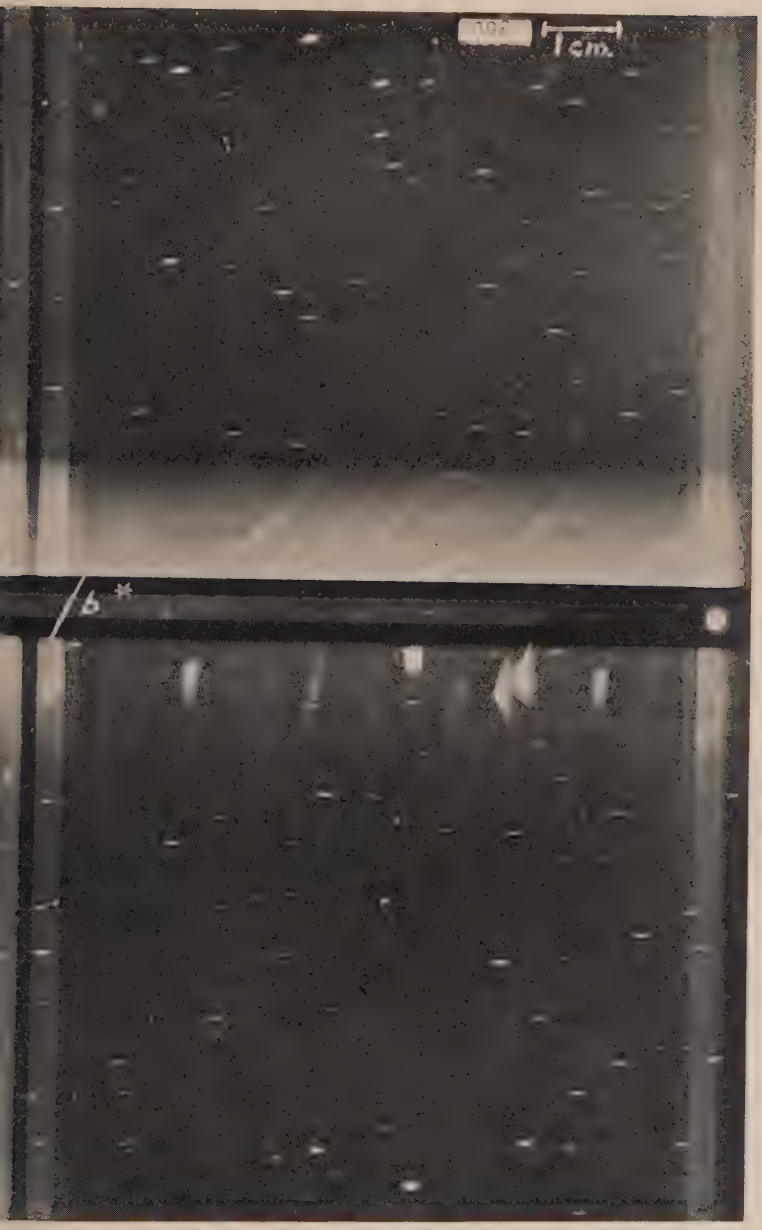


FIG. 3. Aramayoite: zero-layer Weissenberg picture about [001]; Cu-K_α unfiltered radiation; camera radius $90/\pi$ mm.; reciprocal lattice axes are indicated.



g. 4. Aramayoite: first-layer Weissenberg picture about [001]; Cu-K_α radiation, nickel filter.

from the X-ray pictures, gave good agreement with the morphological data:

$$a^* : b^* : c^* = 1{\cdot}0856 : 0{\cdot}9741 : 1$$
$$p_0 : q_0 : r_0 = 1{\cdot}0889 : 0{\cdot}9690 : 1$$

Angular elements of the reciprocal lattice projection are generally not as reliable as morphological measurements; we have, therefore, used the angular relations of the pinakoids, derived from our morphological elements (see table II), for the calculation of the unit cell. The following are the dimensions:

$$a_0 = 7{\cdot}76 \text{ Å.} \qquad \alpha = 100° 22'$$
$$b_0 = 8{\cdot}79 \qquad \beta = 90\ 00$$
$$c_0 = 8{\cdot}34 \qquad \gamma = 103\ 54$$

with $a_0 : b_0 : c_0 = 0{\cdot}8828 : 1 : 0{\cdot}9488$.

This cell contains $Ag_6(Sb,Bi)_6S_{12}$ in the unit and is thus three times the volume of the Yardley cell. Our third-order (010) with the measured spacing 2·81 Å. is equivalent to the second-order (001) of Yardley, with the spacing 2·81 Å. Also the $(\bar{3}\bar{3}1)$ reflection of Yardley with the spacing 1·26 Å. corresponds to our sixth-order (100) with the measured spacing 1·25 Å.

Fig. 3 shows the axial directions as chosen. The periodicities along these directions define the smallest cell consistent with all the reflections. The first-layer picture (fig. 4) corroborates the evidence in fig. 3.

The following table gives a further comparison of some of our spacings and angles with those measured by Yardley:

Index		Measured spacings		Angle to best cleavage	
Yardley.	Berman & Wolfe.	Yardley.	Berman & Wolfe.	Yardley (001).	Berman & Wolfe (010).
(010)	$(\bar{1}01)$	5·67 Å.	—	86° 52′	86° 48½′
(001)	$(0\frac{3}{2}0)$	5·61	5·62 Å.	0 00	0 00
(111)	$(\bar{2}20)$	3·24	3·25	56 10	56 20½
$(33\bar{1})$	$(\bar{6}00)$	1·26	1·25	75 44	75 52
$(\bar{3}31)$	(006)	1·355	1·36	79 07	79 19

Recalculating the Yardley cell dimensions into our orientation:

$$a_0 = 7{\cdot}80,\ b_0 = 8{\cdot}86,\ c_0 = 8{\cdot}26 \text{ Å.},$$

in close agreement with our values, as given above.

Relation to other minerals.—Miargyrite, aramayoite, and matildite have the type formula ABX_2. In the following table a comparison of cell dimensions is given:

	Cell contents.	a_0.	b_0.	c_0.	Reference.
argyrite ...	$8AgSbS_2$	13·17	4·39	12·83Å.	Hofmann[1]
amayoite ...	$6Ag(Sb,Bi)S_2$	7·76	8·79	8·34	Berman & Wolfe
tildite ...	$4AgBiS_2$	8·14	7·87	5·69	Ramdohr[2]

Aramayoite and matildite are similar in two dimensions and the c_0 the latter is about $2/3b_0$ of the former. The b_0 of miargyrite is almost if of the b_0 of aramayoite, but the other dimensions are not simply ated.

W. Hofmann, Sitzungsber. Preuss. Akad. Wiss., Phys.-math. Kl., 1938, p. 111. .A. **7**–387.]

P. Ramdohr, Fortschr. Min. Krist. Petr., 1936, vol. 20, p. 56; Sitzungsber. euss. Akad. Wiss., Phys.-math. Kl., 1938, p. 82. [M.A. **7**–104, 354.]

An electromagnetic separator for mineral powders.

By R. C. Evans, M.A., Ph.D., B.Sc.

Department of Mineralogy and Petrology, University of Cambridge.

[Exhibited June 8, 1939.]

THE use of a magnetic separator for the separation of certain ores has long been a standard commercial practice and a laboratory scale instrument applying the same principles to the separation of mineral grains from a powdered rock has been designed by Hallimond.[1] In this apparatus the mineral grains are spread on a rotating pan which carries them below the pole pieces of one or more electromagnets, the pole pieces being so designed that the grains pass through a strongly diverging magnetic field and so are subjected to a force proportional to their susceptibility. If this force exceeds the weight of the grains they are attracted and adhere to the pole pieces. The material thus collected is periodically discharged by interrupting the magnetic field and the grains then fall through a slot in the rotating pan into a receptacle below.

The instrument here described resembles in principle that designed by Hallimond, but incorporates a number of modifications which experience has shown to be desirable. In particular, attention has been given to the following general points:

(1) The mechanical design has been made very robust in order to ensure trouble-free operation over long periods of time, so that if necessary the apparatus may be allowed to run for hours on end when large quantities of material are to be handled.

(2) As far as possible the apparatus has been made dust-proof and easy to clean. Thus all connecting wires are concealed and exposed surfaces are smooth and free from encumbrance.

(3) Trouble from electrical contacts has been eliminated by the use of a mercury switch to control the magnets and of a brushless induction motor for the drive.

A general view of the apparatus is shown in fig. 1. The pans (1) are turned from a heavy brass disk and are carried on a vertical steel shaft

[1] A. F. Hallimond, Min. Mag., 1930, vol. 22, p. 377.

lounted on ball-bearings. This shaft is driven at six revolutions per inute through a gear train by an electric motor, both the motor and ears being housed in the aluminium casting (2) which forms the base the machine. The mineral grains are deposited on the pans by the opper system situated under the cover (3) and described in more etail below. They are carried beneath the pole pieces (4) of the two agnets and any grains which are unattracted are finally swept from

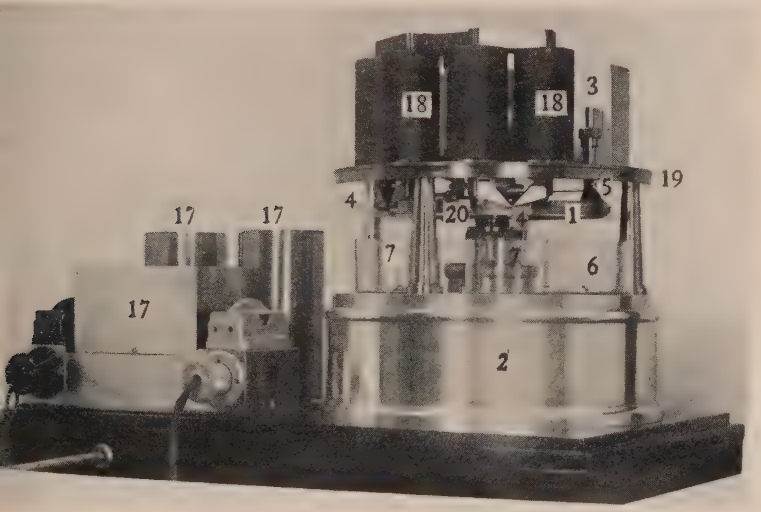


Fig. 1. Electromagnetic separator.

e pans by the brush (5) and fall into the glass receptacle (6). The ner receptacles (7) receive the material dropped from the two magnets nen the magnetic field is interrupted. Other special features of the achine are best described separately.

The hopper system is shown in fig. 2 and is designed to spread the neral grains in a uniform layer over the full length of each pan, thus rmitting a much faster rate of delivery than if the grains were dropped one point only. The grains are placed in the hopper (8), the bottom which is closed by the door (9). This door is carried on a steel spring 9) and is opened momentarily by a magnetic impulse obtained by charging a condenser through the electromagnet (11). This magnet carried on a lever (12), and by means of the screw (13) the opening the door (9), and therefore the quantity of powder delivered, can be

delicately regulated. From (9) the powder falls on to the upper end of the sloping tray (14), which is also mounted on a spring (15) and is tuned to resonance with an alternating current passed through the electromagnet (16), being thus maintained in a state of continuous vibration. The powder is in this way gradually shaken from the tray on to the rotating pans (1) below. The amplitude of the vibrations of this

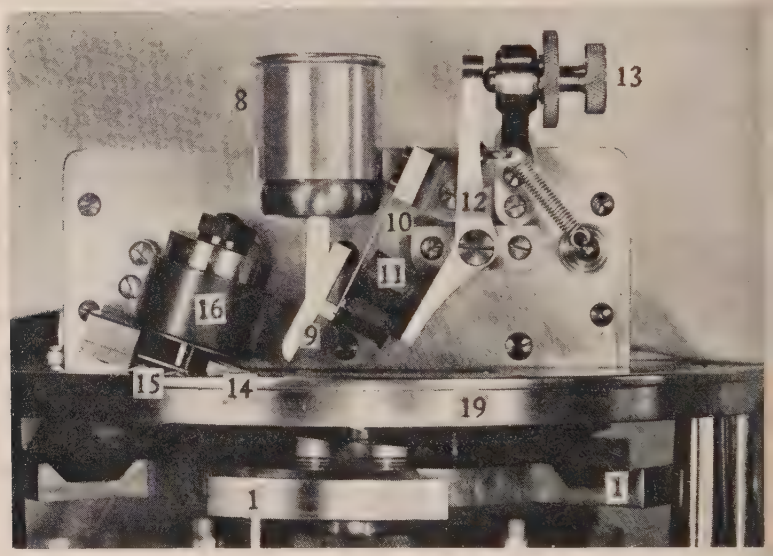


Fig. 2. Hopper system of electromagnetic separator.

tray can be adjusted by withdrawing the pole piece of the electromagnet (16), but in practice it is not found necessary to make use of this adjustment once a suitable setting has been found. In order to handle powders of different grain-sizes, which travel down the vibrating tray at different speeds, provision is made for adjusting electrically the instant of operation of the door (9) relative to the arrival of a pan below the end of (14). For ease of cleaning, the hopper (8) can be removed, and it, the door (9), and the tray (14) are all rhodium plated to provide an untarnishable and virtually unscratchable surface. During operation the whole of the hopper system is enclosed in the brass box (3) (fig. 1). The condenser and other electrical apparatus for the operation of the hopper are contained in the boxes (17) seen to the left of the apparatus in fig. 1.

The magnets (18) are made of a special high permeability mild steel which is easy to machine and yet has a low retentivity, and the two

re identical. All the pole pieces (4) were machined together in one peration to ensure that the magnets are at exactly the same height bove the pans. The magnets are rigidly fixed in the heavy brass late (19).

The current for the magnets is drawn from the direct-current mains sing banks of lamps as regulating resistances. Switches enable the trengths of the magnets to be varied independently by the selection f any combination of these lamps. If desired, both magnets can be f the same strength and it is sometimes convenient to operate under hese conditions, for then the material collected on the second magnet ives some indication of the efficiency of separation at the first magnet y showing the amount of material which it has failed to collect. In ddition to the provision for varying the strength of the magnets, rrangement is made for adjusting the height of the pans relative to he pole pieces. In practice, however, it has been found that it is not ormally necessary to make use of this adjustment once the optimum tting has been discovered.

No weak magnet is provided to remove magnetite or other very trongly magnetic minerals, and if these are present in any considerable uantity they are best removed first with a hand magnet.

The magnets are switched on and off by a mercury switch mounted n a lever in the aluminium base of the apparatus and tripped by a am driven directly from the gearbox. The cam mechanism is designed o give a very abrupt operation of the switch in both directions. Experi- ents with a cathode ray oscillograph showed that the magnetic field ractically reaches its final value in 1/70 second after the operation of he switch, so that no difficulty is to be anticipated due to delay arising om the time constant of the magnet.

In order to eliminate trouble due to material continuing to adhere o the magnets after the current has been cut off, due to the retentivity f the steel, the circuit is so arranged that a small reverse current then asses through the coils of the magnets and demagnetizes them com- letely. At the same time small hammers (20), operated by a castellated ead mounted on the central spindle above the pans, drop on to the ole pieces to dislodge the adhering particles.

During operation the pans and collecting receptacles are protected om dust and draughts by a cellophane shield, not shown in fig. 1, hich spans the gap between the top of the aluminium casting (2) and he plate (19). When not in use the whole apparatus is protected by a ooden cover.

Preliminary tests of the instrument have shown that it is capable of giving a good separation of mineral powders over a wide range of particle size. It is normally not possible to achieve a complete separation in a single operation except in rather favourable cases of minerals of widely different susceptibilities, since with an anisotropic material the force with which the particles are attracted must always depend upon their chance orientation relative to the magnetic field. For this reason it is generally most satisfactory to subject the material to several successive fractional separations with a fast rate of delivery from the hopper and with one or both magnets of strength only just sufficient to attract the mineral required. Details of technique must, however, depend upon the particular circumstances of each individual case and experience soon teaches the most profitable method of operation.

It is a great pleasure to express my thanks to Mr. H. C. G. Vincent who suggested several features of the apparatus and from whose considerable experience of separators I was able to profit in its design. The instrument was constructed in the workshops of the Department of Mineralogy and Petrology, Cambridge, by Mr. A. N. Lanham, to whom also I am much indebted not only for the quality of his workmanship, to which the successful operation of the apparatus is largely due, but also for the many detailed points of the design for which he is responsible. In its present form the commercial manufacture of such a separator would necessarily be rather expensive, but in the light of the experience gained it might be possible to design a somewhat simplified form of the apparatus, incorporating, however, all the essential features of the present machine, which could be manufactured at a moderate price, provided a demand for several instruments could be anticipated. If any readers are sufficiently interested in this proposition I shall be glad to give the matter further consideration.

Petrological application of the low-power binocular microscope.

A. Kingsley Wells, D.Sc., F.G.S.

Reader in Geology, King's College, University of London.

[Exhibited March 9, 1939.]

IN carrying out a petrological examination of pebbles collected by Mr. F. Gossling from the Lower Greensand of Surrey and west Kent, the writer has found a low-power dissecting binocular microscope an extremely useful piece of apparatus. The instrument, by Watson, is fitted with two pairs of objectives on a rotating nosepiece, and with two pairs of eyepieces, so that it commands the choice of four different magnifications.

The pebbles are treated in a uniform manner. After the preliminary examination of a 'bag' of pebbles, those selected for study are ground flat on one side, finishing on the fine carborundum plate as if for section making. Each one is then mounted on the usual 3 by 1 inch glass slide, taking care not to over-cook the balsam. If the pebbles are treated systematically in batches of six, a dozen pebbles can be mounted in less than an hour, so that the gain of time over section-making is very considerable.

The stage of the microscope is a large rectangle of ground glass fitted to the base of the stand; but it has been found greatly advantageous to construct a special, though very simple, fitment consisting merely of two hard-wood strips, an inch by a half, with an inch gap in between, or more if desired, to accommodate the pebble. The wood strips rest on the ground glass and are fastened together with brass strips which overlap the glass stage, thus preventing the former from slipping. The pebble-mount is clipped in position upside down, and is ready for examination through the glass on which it is mounted. For the best results it is essential to use really strong illumination. The writer uses a focusing microscope lamp by Leitz, with the beam concentrated down to give intense illumination of the polished surface.

Under these conditions oolitic cherts ('silicified oolites') and similar rocks become very beautiful and instructive objects. In the majority

of cases the matrix is clear quartz or chalcedony in which the small ooliths are packed. The latter are seen stereoscopically in full relief. Their forms and relations are apparent at a glance. As many of them are seen in section too, the shapes of the nuclei, the nature and disposition of the impurities, and the details of the internal concentric and radial structures are beautifully displayed. In experience it has been found that the stereoscopic examination of a pebble supplements considerably the information gained by study of a thin section, and has more than once corrected wrong conclusions drawn from such. One simple illustration will suffice. The thin section of a spherulitic chert shows vaguely defined spherulites which, in a very few cases, exhibit a small centrally placed opaque nucleus. The pebble-mount, however, is a fascinating object: it is transparent to quite a depth, and several 'layers' of spherulites can be seen as chains, groups, or isolated greyish orbs sufficiently translucent to show an opaque white nucleus at the centre of each without exception. Significant facts are clearly displayed, that might otherwise be deduced only with difficulty from the thin section.

In mounts of rhyolites the phenocrysts of β-quartz display their three-dimensional form to advantage; the familiar curved lines of inclusions are visible as planes, while the minute gas-filled cavities appear as brilliant points of light, and the 'corrosion inlets' as flask- or finger-like protrusions of the groundmass into the body of the crystal.

In some cases, of course, a higher magnification is required. If so, the pebble mounts can be studied quite satisfactorily under the ordinary petrological microscope, using the same strong surface illumination; or again, if a thin section also is required, it is already half made, though it is necessary to remount the pebble on stouter glass before cutting close to the smoothed surface.

The examples cited do not, of course, exhaust the list of rocks suitable for this treatment: a pebble-mount of an organic chert, for example, may be far more informative than several serial thin sections.